Interdepartmental collaboration for A-level mathematics and physics revision

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A Research & Development Project

Submitted for the MSc in Learning & Teaching 2022

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Interdepartmental collaboration for A-level mathematics and physics revision

Abstract

The aim of this project was to establish sustainable collaboration between a mathematics teacher and a physics teacher for A-level revision of their respective subjects and to evaluate its impact on those involved. The review of the existing literature led to research questions exploring the overlapping topics between mathematics and physics, thoughts that students and teachers hold about collaborative revision for A-level mathematics and physics, and the effect that collaborative planning for revision of overlapping topics in A-level mathematics and physics have on students and teachers. For the intervention, two teachers prepared resources on three overlapping topics, first independently and then collaboratively. The collaboration consisted of a task-design session, and a follow-up discussion. Subsequently, the intervention was comprised of three revision lessons, as well as the exploration of the effectiveness of the collaboration through questionnaires completed by students and teachers, and task analysis. Additionally, semi-structured interviews were used to investigate student and teacher perceptions of collaboration, and assessment analysis was used to evaluate student progress. Findings suggest that although teachers hold positive perceptions on collaboration, they identify many barriers to enabling such practices in day-to-day teaching, and therefore are hesitant to commit to regular collaboration unless support and time are provided. The sessions were perceived as valuable and useful by the students and the teachers and there is some evidence to suggest that some of the tasks prepared had a small positive impact on the level of confidence of some students. There is also a strong case for encouraging this kind of collaboration for teaching, rather than revising, of the overlapping topics.

Table of Contents

Introduction *4*

A critical review of the literature *6*

Linking maths and physics education **6**

Describing interdisciplinary collaboration **9**

Effects of teacher collaboration **12**

Challenges of collaboration **16**

How to introduce collaboration? **19**

Theoretical framework **21**

The scope of this assignment **26**

Methodology *27*

Context **28**

Participants **29**

Research plan **31**

Data collection **33**

Questionnaires 33

Semi-structured interviews 34

Data analysis **35**

Limitations of this study **35**

Ethical considerations **37**

Findings *39*

RQ1 Which mathematics and physics overlapping topics do teachers want to collaborate on and why? **39**

Overlapping topics 39

Differences within the overlapping topics 41

RQ2 What do students and teachers think about collaborative revision for A-level mathematics and physics? **43**

Perceptions of the benefits of interdepartmental collaboration 43

Barriers to and for collaboration 47

Thoughts on the revision sessions 50

Suggested improvements 53

RQ3 What effect does collaborative planning for revision of overlapping topics in A-level mathematics and physics have on students and teachers? **55**

Levels of confidence 57

Analysis of the tasks and tests 63

Discussion, conclusions and implications *65*

References *71*

Appendix 1 – Teacher questionnaire *79*

Appendix 2 – Student questionnaires (beginning of lesson) *82*

Appendix 3 – Student questionnaires (end of lesson) 86

Appendix 4 – Task specifications 88

Appendix 5 - Usefulness of the revision sessions reported by student. 90

Appendix 6 - Confidence shifts and time since last encounter of the topics in physics and mathematics by task type and topic. 91

Appendix 7 – Comments on tasks completed by students. 93

Appendix 8 – Analysis and comments on physics assessment. 95

Appendix 9 – SUVAT responses from Student 10. 96

Appendix 10 – Letter to the headteacher 100

Introduction

In the past it was common for initial teacher training providers to offer joint training in maths and physics. This is no longer the case, despite the fact that conversations between teachers of maths and physics (or science, more generally) often express that they should co-operate more frequently, since certain concepts are taught in both curricula. A-level mechanics provides an example of a topic where many concepts overlap and, despite covering it in two separate subjects, many students still find the topic challenging. These observations resonate with the common finding that students often find it difficult to transfer knowledge and skills between disciplines (Dodd & Bone's, 1995).

While teaching maths and physics in a state secondary school in England, I noticed how the experience of teaching mathematics helped me deliver physics content more effectively, and vice versa; how the knowledge of physical contexts helped me demonstrate the applicability and usefulness of mathematics, providing students with extra opportunities to master material. Considering these past experiences, a collaborative approach to maths and physics seems like a worthwhile pursuit.

The national agenda for STEM education, which calls for an increased collaboration between faculties and integration of the curriculum (Honey et al., 2014; Millar, 2020; Wong & Dillon, 2020), provides the final incentive to investigate the ways in which effective and successful collaborations between maths and science can be established. Recently, in their research review on science, Ofsted has advocated for coherent maths and science curricula, and recommended that the departments collaborate more closely together (Ofsted, 2021).

Unfortunately, there is limited literature exploring how collaboration might be implemented effectively on a teacher level (as noted for example by Wong and Dillon (2020)). In fact, for years there have been calls for further research into how science and mathematics departments could collaborate (e.g. Osborne, 2011). The research that does exist on collaboration is mostly theoretical, highlighting the challenges and barriers to collaboration, without further explaining how to establish sustainable collaboration. In addition, yet another gap in collaboration research is the poor distinction between teaching as introduction of new content, as opposed to revision and consolidation of knowledge. The limited number of studies in both the introduction, as well as revision and consolidation of content, demonstrates the need to explore this topic further.

Currently teaching in an independent sixth form college with an 'interactive and informal' teaching approach, and with the backing from the leadership (which was shown to be important for successful collaborations (Wong & Dillon, 2020)), presents the perfect opportunity to address the topic. Initial conversations with teachers have revealed that interdepartmental revision sessions would be the preferable form of collaboration and, given that at present similar content is not delivered synchronously in maths and physics, collaborative revision presents an appealing way forward.

This project looked to establish sustainable collaboration practices between maths and physics teachers for A-level mathematics and physics revision. It brought together two teachers to develop resources that would help A-level students prepare for exams. The collaboration took form of a task-design session, as well as revision lessons that were prepared jointly by maths and physics teachers. The intervention explored teacher and student perceptions through questionnaires and semi-structured interviews, as well as student progress through analysis of assessment and student responses to

diagnostic questions. The sustainability of this collaborative effort was evaluated in terms of the likelihood of these kinds of revision sessions to take place in the future.

The overarching question for this project was: how can I implement a form of collaboration in my own school? When looking to answer this primary question, a number of sub-questions emerged. What is the rationale behind linking mathematics and science education? What does it mean to be interdisciplinary? What might interdisciplinary collaboration look like? What could be the effects of collaboration, positive or negative? What factors might enable or hinder collaborations? How can new collaborations be implemented? What could a sustainable collaboration look like in my school? These questions will be explored in the literature review.

A critical review of the literature

Linking maths and physics education

Mathematics and science education is an area of research that has grown over the years with attention mostly being given to exploring the relationship between the subjects from a variety of angles. According to Berlin and Lee (2005) this ever-expanding field, which had a very significant impact on the education sector, focused mostly on middle school up to 1989, before shifting to secondary education more generally. Currently, mathematics and science education is an `area of concern across all levels of schooling and beyond relying on the strong links and shared values that exist between the disciplines (Honey et al., 2014; Millar, 2020). Moving beyond these two disciplines, a movement has emerged to link not only mathematics and science, but also technology and engineering. As a result of this, STEM (Science, Technology, Engineering and

Mathematics) has become a commonly recognised term that has been applied in numerous fields.

In line with the expansion of research on integrated education beyond middle school, the popularity of STEM has grown significantly over the last 20 years. Today it is widely used in education, research, policy, and industry, with scholars such as Millar (2020) seeing it as more than just an umbrella term, but also as a conceptual tool to improve teaching and learning, economy and innovation, and other fields. In addition to the more conceptual reasons for linking the disciplines (such as, supporting students in making connections between disciplines), Millar (2020) argues that with the modern world becoming more complex and multidimensional, a more integrated and interdisciplinary approach to education - one that better prepares people for further education and the modern job market - is the necessary step forward. This could be beneficial not only to individuals entering STEM professions, but to those pursuing other career paths as well. As Williams et al. (2016) point out, people working in non-STEM humanities and social-science areas are also in need of an improved mathematics education, one that is linked to their own area of expertise. Even though these views are shared by a number of researchers (e.g., Becker & Park, 2009; Geiger, 2019; Honey et al., 2014; Wong et al., 2016), most education providers today still follow a disciplinary approach to teaching, with subjects being taught in isolation, and with little to no integration of curricula.

While it might often be useful to view STEM disciplines collectively, unique connections between any two disciplines maybe worth exploring too. As a result, this paper will focus on the link between mathematics and physics only, which is motivated by the context this study is set in.

Mathematics and physics hold a special connection (Orton & Roper, 2000; Redish & Kuo, 2015), due to a significant overlap in content and the extensive reliance of physics on mathematics. For example, both subjects teach mechanics at A-level (Pearson Edexcel, 2018; Pearson Edexcel, 2020). However, even though they share common themes and the potential to benefit from an interdisciplinary approach, Doig and Willams (2019) highlight that mathematics has the tendency of being treated as a 'black box', or a tool, for other disciplines, including physics. They fear that, without a more rigorous approach, interdisciplinary mathematics education might not reach its potential to become a conceptual tool that could improve pedagogy. This links directly to some of the other gaps in the literature identified by the authors, such as the need for a deeper understanding of how different disciplines (e.g., mathematics and physics) are related, and what aspects of mathematics enable interdisciplinary approaches. They also suggest that in future research "case studies need to be clear about the phenomena they are researching" (Doig & Willams, 2019, p.299), in order to make meaningful contribution to the field.

Despite numerous calls for interdisciplinary education, implementing such an approach is not an easy endeavour. Some of the other gaps highlighted by researchers include, but are not limited to, lack of agreement about what concepts are important for describing interdisciplinary studies, and the lack of commonly adopted theoretical frameworks (Williams et al., 2016); the current failure to understand impact of disciplinary and interdisciplinary approaches, and the lack of guidance on how to incorporate interdisciplinary learning more successfully (Millar, 2020); lack of instruction on how to develop teaching and the curriculum around subject integration, and little empirical evidence on effectiveness of such approach (Pang and Good, 2000); and many other.

Describing interdisciplinary collaboration

In order to describe interdisciplinary collaboration effectively, it is first important to define the two terms: interdisciplinarity and collaboration. Roth (2014) provides a practical definition for the first: “interdisciplinarity denotes the fact, quality, or condition of two or more academic fields or branches of learning [which] cross the traditional boundaries between academic disciplines” (as cited in Williams et al., 2016, p. 22).

Around the time the focus of integrated mathematics and science educational research started shifting to secondary schools, Little (1990) proposed a refinement to the concept of collaboration, presenting it as a continuum which consists of more independent forms of storytelling and scanning, sharing, aid and assistance, and joint work. The author argued that more independent forms of collaboration are not as common, since they have a higher need for mutual autonomy and initiative, and that positive impact can only be obtained if they are facilitated by meaningful co-labouring.

For many years describing collaboration has been challenging due to the lack of a commonly adopted terminology (Wong & Dillon, 2020). However, by conducting a review of 82 studies, Vangrieken et al. (2015) provide a solution with a terminological framework for use in collaboration research. Building on the work from Little (1990) and others, they define collaboration as “joint interaction in the group in all activities that are needed to perform a shared task” (p. 23). This definition, which is the one that will be used in this study, is in line with other definitions found in the literature. For example, Woodland et al. (2013) defines teacher collaboration as “teachers working together, and engaging in reflective dialogue, with the common goal of improving practice and increasing student learning” (p. 443), while Kelchtermans (2006) provides a definition of collaboration as a

description, “referring to teachers’ cooperative actions (their actual doing things together) for job-related purposes” (p. 220).

Teacher collaboration can first be broken down into co-teaching and co-planning (Solis et al., 2012). The key difference between the two is that co-teaching inherently requires the presence of two teachers in the classroom, which might not be possible or achievable for many education providers. In terms of collaborative teaching, examples of models most common in literature include: whole class, teacher led model; whole class, team teaching model; two heterogenous, and two homogenous groups.

Apart from the aforementioned division into two subcategories, collaboration can be separated in many other ways (for example, short term or long term) and can be influenced by a range of factors. In their paper, Wong and Dillon (2020) consider different modalities of collaboration and what factors are important in their development. By exploring existing collaborations in sixth English schools, they report that collaboration often takes the form of informal conversations and ‘visiting experts’ (a subject specialist providing a short content input during a lesson in a different subject). These two types were most favoured by those involved, but only given the presence of an external stimulus (often coming from the leadership beyond the teachers or even heads of departments), which in most cases was necessary to initiate and develop collaborations in the first place.

Further clarification and definition of various forms of collaboration also comes from Vangrieken et al. (2015). In addition to defining collaboration, they also put forward a clarification of four other concepts that they consider as other forms of collaboration. They define professional (learning) communities, communities of practice, teams, and groups. A professional (learning) community encapsulates various forms of teacher teams

within a school. These teams are learning-centred and are linked by common goals and values. Although 'community of practice' can be viewed in my ways, the authors of the paper settle for the definition provided by Lave and Wenger (1991) as "a set of relations among persons, activity, and world, over time and in relation with other tangential and overlapping communities of practice" (p. 98). Finally, a team is the collective term for interacting individuals, with shared aims and responsibilities, while a group is a collection of individuals that share a specific social categorisation. What differentiates groups from teams is that in a group, the aims and responsibilities are individual, rather than shared.

Moreover, it is also possible to categorise all the different forms of collaboration defined by Vangrieken et al. (2015) (collaboration, professional (learning) communities, communities of practice, teams, and groups) into two structures: (1) within-grade or cross-grade collaboration; and (2) disciplinary or interdisciplinary collaboration. Some structures are of course more common than others, depending on the context. For example, 'superficial collaboration' is more common that deep collaboration (Vangrieken et al., 2015). By reviewing the literature, authors have found that within-grade collaborations were most common overall (except for high schools), and collaborations mostly occurred across the disciplines (interdisciplinary collaboration). In addition to that, the authors also explain that different forms of collaboration fall on a continuum, with varying levels of focus and depth. The collaborative continuum is based on the degree of entitativity (the quality of being a team), achieved by considering the extent to which the members of a collective share goals and duties, commitments to a given course of action, the sense of identity and belonging to a particular group, and finally, the reliance on each other to follow a course of action and achieve a desired outcome. What focus and depth

of teacher collaboration can offer then is a more detailed assessment of a collaboration, consisting of preserved individualism, coordination, cooperation, and sharing.

Effects of teacher collaboration

Vangrieken et al. (2015), who conducted a systematic literature review on collaboration literature, identified several potential benefits and negative consequences that could arise from collaboration on a student level, teacher level, group level and organisational level. For example, the authors point out that collaboration might improve student learning and understanding, as well as enhance teacher practice and work culture. On the other hand, there exists a possibility for interpersonal clashes, conformity of instruction, and using collaboration for control.

Depending on the form of collaboration, Vangrieken et al. (2015) report that most of the benefits aggregate on the teacher level. These benefits include: teachers more frequently exchanging knowledge, ideas, and experience (which can also reduce teacher isolation, as reported by Ostovar-Nameghi and Sheikhahmadi (2016)), improved effectiveness, communication, motivation, and morale, more innovative approaches to teaching and work, improved goal orientation, decreased workload, and a greater sense of integrity, among others. Apart from the numerous ways in which collaboration can aid the teachers, there are also multiple benefits to students and the school's organisation as well. For example, the improved student achievement, understanding, and learning, more balanced power dynamic between staff and students, improved innovation, a fairer school culture, and a greater overall attention for the needs of the students.

Similarly to Vangrieken et al. (2015), Honey et al. (2014) also point to the potential benefits of collaboration, such as: improved student motivation and interest, as well as

attainment and perseverance. They took this stance based on the literature on cognition, which suggests that interdisciplinary teaching can have a positive impact on retrieval and conceptualisation. However, the researchers do identify that the possible benefits may not be equally distributed between the disciplines. Mathematics is the discipline that gains less from integration, echoing the asymmetry of dependency and of benefit between the disciplines, also identified by Wong and Dillon (2019), which will be discussed in more detail later.

Becker and Park (2009) conducted a meta-analysis of twenty-eight studies aimed to facilitate a better understanding of the impact of integrative approaches across STEM disciplines. They report that integrative approaches carry positive effects overall, but their impact decreases with each stage of education, with largest effects reported at the elementary school level. Additionally, integration of four disciplines was found to generate the biggest impact, with integrations consisting of a fewer number of subjects presenting a lesser effect. The researchers suggest that future research should investigate why mathematics is the subject that benefits the least from a STEM approach, and how students develop mathematical understanding through integrated teaching.

Based on data analysis of PISA 2012 results from Germany, Mora-Ruano et al. (2019) report a small positive effect that is strongly linked to the extent that teachers' have discussed student achievement during their collaborative efforts. Motivated by the increasing call for more collaboration in school settings, the authors report their findings as a result of an investigation into the impact of teacher collaboration on student achievement in mathematics. This finding highlights the importance of a clear and shared goal for the success of a collaborative effort. In this particular case, the teachers have focused on student achievement.

Schleifer et al. (2017), in their guide, report studies that have shown that higher degree of collaboration within schools is linked to improved student attainment (Kraft & Papay, 2014). Collaboration in such schools involved strong communities of practice, shared responsibilities and practices, and meaningful interactions between teachers. However, various practices influence student attainment differently. For example, there is contradictory evidence of teacher mentoring on student attainment, with Papay et al. (2020) claiming positive impact of mentored teachers on student attainment across the whole school, while Glazerman et al. (2010) reporting no changes except for only a small, conditional increase in mathematics and English. Additionally, differences in professional learning communities also lead to varied levels of effectiveness, with those characterised by strong leadership and support from the principal and the senior team experiencing the most positive effect on student attainment (Vescio et al., 2008). Finally, teacher's social capital (skills and resources that could be shared between teachers) and learning from one another, as well as sharing of information and data, can also have a positive impact on students (Leana & Pil, 2006).

The effects of leadership and the support from the principal on effective collaboration are also very substantial. Support from the senior leaders can set a model of collaboration that can serve as a standard down the leadership ladder (Bryk, 2010). The principal also has the power to dedicate time for collaborative practices, without making it an additional burden or a responsibility to fulfil (Kraft & Papay, 2014). With that in mind, it would be important for a principal to decide on the right level of involvement, as collaboration that is too closely monitored and enforced is significantly less likely to foster positive effects (Vangrieken et al., 2015).

Other effects of collaborative practices on teachers indicate improved retention and higher levels of commitment to school's life and teaching (Vangrieken et al., 2015). There are hints that this is linked to improved student attainment, as well as improved morale amongst staff and students. There is also indication, that a collaborative community of practice can acts as a natural form of continuous professional development, which can also have a positive knock-on effect on other things, such as improved satisfaction and teaching (Kasalak & Dağyar, 2020). The underlying reason for these positive effects most likely lies with improved communication and available channels through which staff can be heard, raise concerns, deal with conflicts, receive support, resulting in stronger social ties.

Schuster et al. (2021) investigated existing collaborations in nine German schools in terms of their relation to teacher networks and the school's structure. They have found that the schools where collaboration is more basic or superficial, it is teachers' individual traits and characteristics that have the biggest impact on the quality of the collaboration. In contrast, schools where deeper levels of collaboration have evolved, had pre-existing relationships at the core of their collaborations. The importance of this research lies in the importance of various modes of collaboration in engaging teachers to work together.

Although collaborative efforts can have a positive impact on all areas of school life, there are also possible risks, pitfalls, and negative consequences associated with it. First of all, there is no certainty that the benefits of collaborations will be observed (Kelchtermans, 2006). Secondly, most of the negative consequences aggregate at a teacher and group level. If not implemented correctly, collaborative approaches can give rise to tensions and conflicts within groups (B. Johnson, 2003). Instead of reducing workload they can increase it by adding extra pressures and responsibilities (Bovbjerg,

2006). Instead of fostering innovation they can also lead to conformity and loss of independence, and result in imbalanced power structures (Main & Bryer, 2005). What this means is that individuals can gain increased influence over other colleagues, leading to more closed groups and a standardisation culture. Higher up the school structure, collaboration could also serve as a way of enforcing expectations and implementing standardisation further (Scribner et al., 2007). Interestingly, Kolleck (2019) challenges the claims that teacher collaboration can have a negative impact on autonomy, as many studies show that the opposite is true (see for example, Conley et al., 2004)).

Challenges of collaboration

Based on their review of the literature, Vangrieken et al. (2015) consider prerequisites for effective teacher collaboration, as well as the factors that can enable and hinder such efforts. These can by linked to personal, structural, group, process, and organisational traits, and guidance. Depending on whether various conditions are met or not can be the deciding factor for whether collaboration will be successfull, whether it will be a lasting endeavour, and whether it will foster positive or negative consequences. They argue that collaboration can be facilitated with the right blend of various characteristics. For example, with people exhibiting the willingness to co-operate, and possessing the understanding and the skills required for effective teamwork, one can expect to observe successful collaborations that can lead to various benefits (these were discussed earlier). That of course is also influenced by the types of personalities within the team, leadership, participation, whether the staff have a choice to collaborate or not, the level of autonomy that they can hold within a team, the size of the team, and many other. On structural and organisational levels, it is important for collaborations to have a common goal and a shared vision, clear and suitable division of roles and labour,

consistent meeting times and continuity, support of the leadership, and others. It is clear, that coordination of so many aspects is a difficult task, which leads to the conclusion than establishing effective collaboration is not easy and this it is not without obstacles. Weinberg and Sample McMeeking (2017) also identify four factors to effective interdisciplinary action: teachers' lack of confidence beyond their own field of expertise, time constraints, lack of resources, and existing school structures based on disciplines. Moreover, they also introduce the interdisciplinary pedagogical content knowledge, as the fifth limiting factor for effective collaboration.

One of the main remarks made by Wong and Dillion (2020) is that the collaborations they observed were fragile. For example, the duration of collaborative efforts was identified as a problematic factor. In a case of a long-term collaborative project, they found that the longer the project, the greater the perceived loss of subject specific content. Similar arguments came from Williams et al. (2016) a few years earlier, who argued that meaningful interdisciplinary projects are challenging to design and implement. When addressing the concerns around interdepartmental collaboration, they claimed that "there is nothing obvious to exchange when science and mathematics teachers work together, or no clear benefit to both sides" (Wong and Dillon, 2020, p. 412). Along the same line, a systematic literature review by Margot and Kettler (2019), which looked at 25 articles on teachers' perceptions on STEM education, concluded that even though educators value integrated education, they identify barriers to effective integration of a more interdepartmental curriculum, such as pedagogical and curriculum challenges. Apart from recommending quality instruction, the authors also call for supporting collaboration between teachers. They do not, however, indicate how this collaboration could look like.

Wong and Dillon (2019) also argue that establishing any interdepartmental collaboration between mathematics and science is difficult, and usually not mutually beneficial. They build this argument by identifying an asymmetric benefit component to the mathematics-science collaboration. According to the scholars, although sciences might benefit from working with the mathematics department (for example, through improved attainment scores of the students), the same benefit might not be observed in mathematics (sometimes even stunting students' mathematical progress). This asymmetry was also reported by Orton and Roper (2000) and Honey et al. (2014). Orton and Roper (2000) explored the theoretical landscape of the secondary mathematics and science education literature, as well as the primary education literature, and identified the asymmetry between the curricula (the need of mathematics in science, and the lack of need for science in mathematics) within the relationships between the disciplines at different stages of the educational ladder, In addition to that, they also discussed the absence of synchronization between the curricula, and explored the issue of the lack of mathematical ability amongst undergraduate science students. Honey et al. (2014) conducted a systematic literature review to search for impact of collaborative approaches on learning and attainment, as well as subject interest and identity. They authors noted that although there is evidence for the positive impact of integrated approaches, it is significantly weaker for mathematics. All things considered, an asymmetry between the disciplines need not mean that there are no topics within them that can benefit from a collaborative approach. Looking at mathematics and physics at A-level, for instance, where the curriculum is more closely connected, and where there is a greater overlap than between other sciences, provides a ground for collaboration. Thus, this could be the sought-after foreground where mathematics can benefit from science.

Finally, Redish and Kuo (2015) also identify a common difficulty in effective application of mathematics in the physics classroom by students. They suggest viewing learning mathematics and physics as two similar, yet separate languages (in terms of how knowledge is constructed). This view may help educators to bridge the transfer gap by approaching the teaching of both subjects in different ways, and not assuming that students will be able to apply a given skills or concept straight away.

How to introduce collaboration?

As previously mentioned, research on implementing mathematics and science collaboration is scarce and empirical applications and interventions are particularly rare (Honey et al., 2014; Wong and Dillon, 2020). While shortcomings in matters of terminology have been partly addressed by Vangrieken et al. (2015), who independently collated commonly used terms in this research area, this terminology is still to be adopted by researchers in the field. Additionally, even though researchers offer numerous recommendations, and list multiple conditions and prerequisites for successful collaborations, there are no step-by-step guides that could work in every possible context or promise specific results.

In the collaborations that have been successful there are three concepts, laid out by Hargreaves (2019), that are useful in implementing new collaborations: encouraged collegiality, professional capital, and collaborative professionalism. This effectiveness of such collaborations could then be considered in terms of the associated processes and outcomes (Vangrieken et al., 2015). For processes, there are three main criteria: effort (that individuals invest into collaborative actions), knowledge and skills (that teachers bring and that complement one another), and task performance. In addition to these three criterions, an effective team needs to make sure that they establish clear goals,

roles, and a fair division of tasks. Moreover, when pursuing a particular line of action, a team needs to approach it with flexibility and versatility and utilise the competences of all their team members as well. Finally, a team also needs to keep track of their collaborative efforts and engage in professional development, as well as communicate openly, consult data, and have support from the senior leadership. In terms of the outcomes, effective collaboration needs to be built on clear, mutually agreed goals that are achievable, measurable, and that have the potential to bring practical impact. It is also most beneficial if the prospect of further work is assured (i.e., a given collaboration is not an isolated and individual endeavour). Given the number of prerequisites needed for a collaboration to be successful, it is clear why such endeavours are not easy to implement.

Williams et al. (2016) also collates an argument from a number of sources to suggest themes (topics) as a central prerequisite for interdisciplinary collaboration (see for example, Ackerman, 1989)). Themes, they argue, can serve as a focus and as a guide for constructing collaborative efforts. In order to be effective, they must be relevant for the subjects, support and aid teaching in both disciplines through shared content and allow for learning to be identified and transferred beyond the boundaries of the field of study. Williams et al. (2016) reached these conclusions by assessing a number of large-scale empirical projects on collaboration as well as at two successful case studies of interdisciplinary collaboration. For example, in one of the large-scale empirical studies, a five-year intervention that involved middle school teachers collaborating with undergraduate students on 'discovery-orientated activities' (Shulman & Armitage, 2005). Even though this project raised the student attainment in mathematics and encouraged some of the involved undergraduate students to pursue teaching as a career, it was an endeavour that was demanding in terms of the human capital, time, and the required

level of decision-making and influence within the school. As a result, such studies are unattainable for those wanting to introduce collaboration but lacking these kinds of resources. Unfortunately, the other two case studies also incorporated a large human capital, time involvement, and funding, and even though they led to successful outcomes, they offer very little in terms of informing smaller, teacher-led collaborations.

To summarise, even though a number of studies have shown how collaborations have been successfully implemented at higher levels of school hierarchy, it has been difficult to find any publications that would have shown a perspective of a teacher trying to implement a collaborative approach in their own setting. This echoes the importance of the support from the leadership for the success of collaborative efforts (Wong & Dillon, 2020).

An investigation that is perhaps the most relevant and important for this project came from Triantafillou et al. (2021). The researchers present a study of teacher educators supporting mathematics and science teachers in a collaborative design and delivery of curriculum tasks. They approach their analysis using activity theory and expansive learning cycle to explore the actions and the aims of teacher educators. They report that collaborative actions were generally focused on content, and highlight those interactions played an important role in overcoming obstacles and enabling teacher educators' professional development.

Theoretical framework

The field of interdisciplinary collaboration suffers from a lack of commonly adopted tools and frameworks, and a lack consistency in theoretical approach, leading to conflicting findings (Kolleck, 2019). It is important to acknowledge that research into some aspects of collaboration does make use of more established theories and frameworks (for

example, motivational models which assess motivation in collaborative settings, such as expectancy value theory (Wigfield & Eccles, 2000) or social cognitive theory (Bandura, 1986)). However, when it comes to assessing collaboration, there are not many theories that can capture it, and researchers settle for either no specific theoretical approach or adapt an existing one. For example, Hackman and Oldham's 1980) work group effectiveness model used in the study from Conley et al. (2004) on teacher work group effectiveness. Finally, in some cases, researchers also propose new frameworks or use ones that have not gained popularity yet. For example, Gerdes et al. (2020) put forward an interdisciplinary collaboration framework that is based on knowledge sharing, joint work, and trust. Although this framework proved useful in capturing the positive effect of senior leadership's support on cross-curricular learning, it was quite limited in terms of the range and the depth of concepts it incorporated. As a result, it is not robust enough to be applicable in a wider range of contexts.

Even though the study presented by Triantafillou et al. (2021) focused more on the effects of collaboration on the educators rather than those of teachers or students, it offered a theoretical approach to describing collaboration in a setting similar to the one of this project. As mentioned earlier, the researchers used activity theory to explore actions and aims of teacher educators during a collaborative effort. Similar theoretical lens was also adopted by Williams et al. (2016) to describe disciplinarity and interdisciplinarity from a historical perspective.

Activity theory is a theoretical approach to viewing actions through the lens of interactions between the community, the division of labour within, subjects, objects, artefacts, and instruments, which are bound to rules, and which aim to reach a specific outcome. The motive for any endeavour is then mediated by intrinsic tensions and

contradictions between the different parts of the system. The strength of this framework lies in the way it connects an individual with its social context and the environment. Limitation of activity theory on the other hand, is linked to its lack of consideration for some other factors that may affect the relationships between the different elements within the activity system, such as personal characteristics or socio-economic background.

Figure 1 represents a simplified human activity model that was adapted from Engeström (2015, p.63). Originally, the model also included the elements for production,

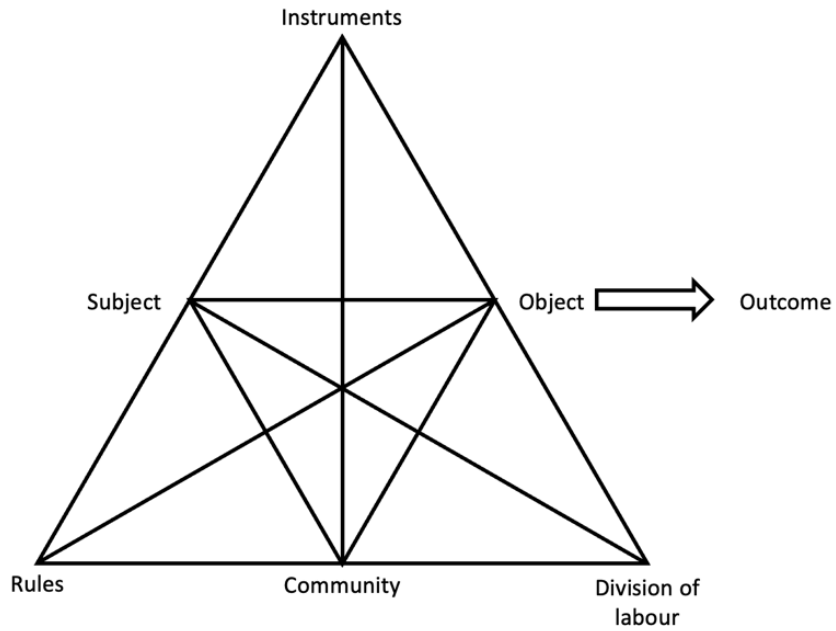


Figure 1. Simplified adapted human activity model (Engeström, 2015, p.63).

consumption, exchange, and distribution, which were omitted by Triantafillou et al. (2021) in the adaptation of the model to educational settings.

Williams et al. (2016) also adapted the framework from Engeström (2015) to describe disciplines. However, they developed it further in their effort to explore interdisciplinarity. Figure 2 shows their model of interdisciplinary collaboration as two distinct activity systems working together towards a shared outcome, with production as an additional element of each system, as compared to Triantafillou et al. (2021).

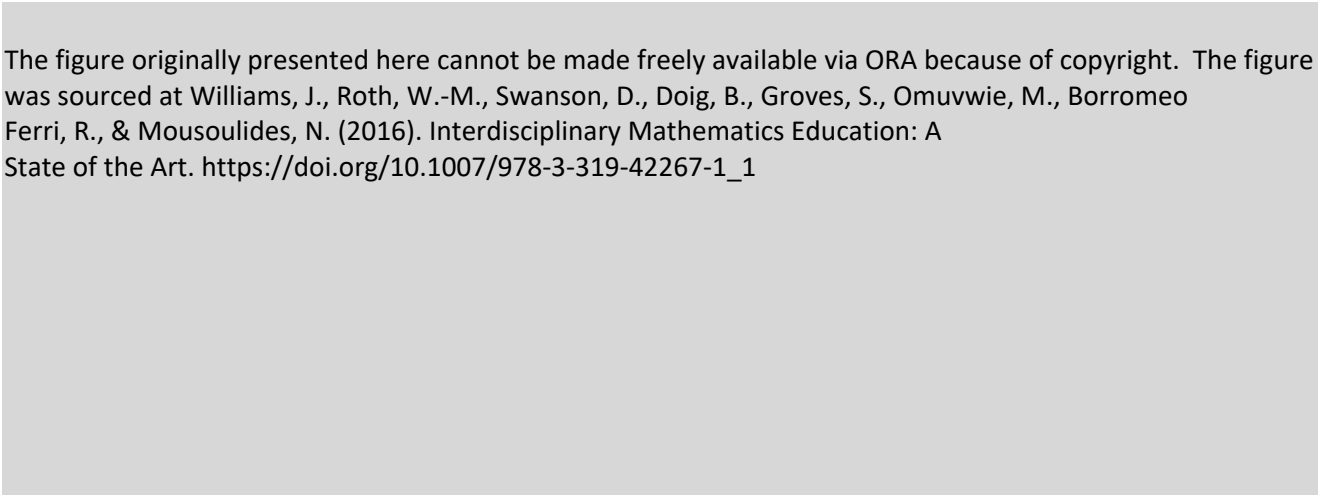


Figure 2. Interdisciplinarity - two activity systems working together towards a shared outcome (Williams et. al. (2016).

Williams et al. (2016) explain that this way of representing interdisciplinarity offers a robust way of exploring and designing collaborations. The authors highlight that collaboration is a dynamical process where "the work of the collective involves transforming the 'raw' objects into 'outcome' objects that meet social needs" (p. 10). By considering the relationships, tensions, and contradictions between the various elements in respective activity systems, one can gain insight into why some collaborations work and some do not, why some efforts lead to certain outcomes and why some fail to do so, and what to focus on when implementing new forms of collaboration. However, such an approach also requires careful consideration of contradictions and pitfalls. For example, a collaborative project might involve two groups working towards a common product but different outcomes, which could lead to the effort being deemed unsuccessful.

Task design and transfer

Task design and transfer of knowledge are two concepts that are relevant to this study but are not explored in great depth. They are relevant because this project will involve teachers collaborating on a curriculum task that will require students to transfer knowledge across the disciplines. As a result, potential outcomes of this intervention

might also be considered in terms of task design or transfer of knowledge, rather than collaboration. However, they are not the aim here, but rather a medium through which the end-goal can be achieved.

Considering task design is important for efforts that are concerned with improving mathematical outcomes (H. L. Johnson et al., 2017). According to Geiger (2019) task design is in turn affected by pedagogical design capacity (the approach to teaching that capitalizes on existing resources). The author acknowledges that being a difficult process, task design requires careful consideration of intent, curriculum relevance, and resources that are already available.

Frade et al. (2009) use the definition of transfer of knowledge as "the use or application in one context of knowledge learned in another" (p. 14). They distinguish between views of knowledge as something stable and lasting (a cognitive perspective), and as an activity that can be collectively shared within a given setting. They also consider "transfer in Bernstein's (1996) terms, as the transfer of knowledge between two insulated domains or vertical discourses" (p. 14).

Dodd and Bone (1995) explore the problem of students often failing to apply mathematics in the science classroom. They consider this issue by analysing views held by high school teachers in three different school and year nine students. They provide a useful and important observation: students are often not prepared to tackle certain aspects of the content due to misalignment of the curricula and the lack of appreciation on the side of science teacher for the difficulties that students face with mathematics.

Additionally, Frade et al. (2009) explore the problem of transfer between mathematics and science, by looking at interactions between two teachers (one mathematics and one science) in an elementary and secondary school. By considering the

existing boundaries between the disciplines, they pay a lot of attention to the ideas of situated learning and community of practice. They see the mathematics and science community of practice as something that arises from interactions between relevant actors, encompassing various practices and efforts linked to collaborative work. The authors argue that this construct can be beneficial in aiding understanding of how students transfer knowledge across boundaries between various disciplines. Regarding the role of the teachers and the level of conformity about pedagogical and subject-related values also require consideration, as well as the teachers' willingness to cross interdisciplinary boundaries. This can, for example, involve a curriculum that is more easily accessible to non-specialist educators. Regarding the role of the students, the focus should be placed on an open-minded attitude towards interdisciplinary practices, meaningful interactions between students and teachers, and making connections. The authors finally point out that the outcomes of newly established communities of practice should also be viewed and evaluated from a collective point of view (for example, by looking at all students involved), rather than an individual one.

The scope of this assignment

This project grounded some of the considerations from the literature within the school context to conduct an explorative investigation looking at establishing a co-planning interdepartmental collaboration for revision of mathematics and physics. This intervention used the terminology suggested by Vangrieken et al. (2015) and the interdisciplinary activity theory by Williams et al. (2016) to describe a collaborative effort that a) compared the overlaps between the mathematics and physics curricula; b) brought teachers together to design revision sessions on an overlapping topic; c) carried out the

revision sessions and evaluated them through teacher and student perspectives, as well as student work. There are three research questions that originate from these aims:

> RQ1 Which mathematics and physics overlapping topics do teachers want to collaborate on and why?
>
> RQ2 What do students and teachers think about collaborative revision for A-level mathematics and physics?
>
> RQ3 What effect does collaborative planning for revision of overlapping topics in A-level mathematics and physics have on students and teachers?

The first research question linked to Wong and Dillion's (2020) observation that finding suitable points of connection between the subjects is essential for collaboration. It also acknowledged the special connection between mathematics and physics (Redish & Kuo, 2015) and appreciated that understanding teachers' beliefs about collaboration is important for effective implementation of STEM strategies (Margot & Kettler, 2019). The second research question aimed to explore the ideas that students and teachers hold about a collaborative approach to mathematics and science. Many papers look at teacher's perceptions on collaboration (for example Wong and Dillon (2019)), but no studies seemed to have investigated what do students think about such an approach. Additionally, this research question hoped to gather ideas that would inform future collaborations at the school. Finally, the third research question tried to determine what effect (for example, on student levels of confidence) a collaborative mathematics and physics revision lesson could have on students, linking to numerous calls for more research on collaborative teaching.

Methodology

This practitioner research project was exploratory in nature and comprised of three parts, with each part involving different participants, research instruments, and

addressing different RQs. The first part included the comparison of the mathematics and physics subject specifications and involved two teachers collaborating together. The second part, consisting of three interventions, had students participate in revision sessions on overlapping topics. The final part was made up of post-intervention semi-structured interviews that included the teachers and the students.

Context

The school where this study was undertaken implements a disciplinary subject structure on a student level (subjects are taught in separate classes) and an interdisciplinary subject structure on a managerial level (mathematics and science belong to the same curriculum group). Changing the entire structure of the school to accommodate some forms of collaborations was not feasible, practical, or ethical, within

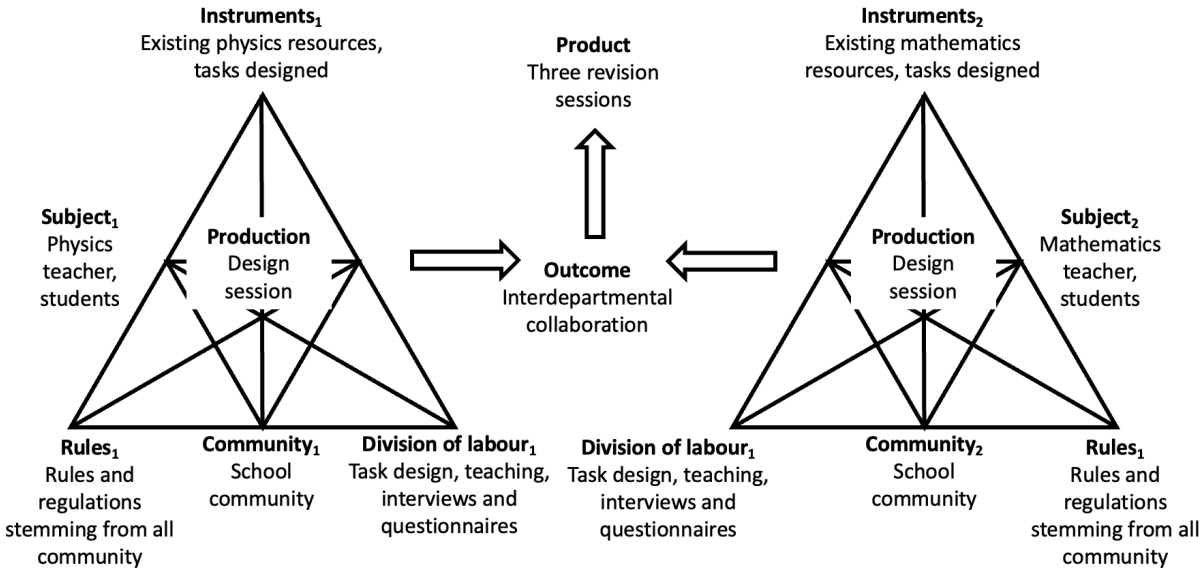


Figure 3. Adopted model for interdisciplinary collaboration.

the timeframe of this project. In order to enable meaningful and practical collaboration between mathematics and physics teachers in this context, it was therefore only plausible to build on the existing structure of curriculum delivery and look at supporting transfer and higher order learning through teacher interactions outside of lessons.

Figure 3 shows an adaptation of the interdisciplinary collaboration model from Williams et al. (2016) to show the relationship between physics (activity system 1 – left) and mathematics (activity system 2 – right) in this context. This project will rely on instruments, subjects, and division of labour, but will be limited to some extent by constraints, commitments, and obligations, linked to the school community (the structure of school's subject-oriented system), and rules (timetabling as well as time and curriculum constraints).

Participants

Altogether, 10 mixed ability students from year 12, taking mathematics and physics at A-level, participated in this study. Externally divided into two physics classes (of six and four) and three mathematics classes (with eight of the students in one mathematics class, and the rest in two separate mathematics classes), all of the students that took part in this study were students with English as an additional language. Their language levels, which were based on their most recent International English Language Testing System (IELTS) scores (at the time of intervention), varied from modest to expert (native). The students also came with various levels of prior attainment in both subjects. For information on students' level of English and prior attainment, please refer to Table 1.

Student	English level	Prior attainment (Physics)	Prior attainment (Maths)
1	Modest	High	Middle
2	Modest	High	Middle
3	Modest	Middle	Middle
4	Modest	Low	Middle
5	Modest	Low	Low

6	Good	Middle	Middle
7	Good	High	High
8	Competent	Middle	Middle
9	Competent	Middle	Middle
10	Expert / Native	Middle	Middle

Table 1. Students' levels of English and prior attainments.

Out of the two physics teachers and three mathematics teachers that regularly worked with these students, only one physics teacher, and one mathematics teacher were selected for this study. This was motivated by: (1) as one of the physics teachers for the cohort, my direct involvement in the task design session could have introduced an additional degree of bias; (2) the other two mathematics teachers did not teach any of the overlapping topics; (3) the number of available physics teachers (one) imposed a limit on how many mathematics teachers could be recruited to maintain an even split of input within this collaborative effort; (4) in order to introduce a level control for pedagogical content knowledge (which Weinberg and Sample McMeeking (2017) identified as an important factor for effective teacher collaboration), teachers with similar teaching experience and level of education were the ideal candidates for this study. The teachers that were selected had similar levels of experience (around five years in teaching), similar levels of education (both have completed doctoral degrees), and similar roles held within the school (both have been working at the school for around a year, as subject tutors).

The teachers who participated in this study were also my main collaborators. Almost every stage of this project was discussed with them, and their views, ideas, and preferences to great extent informed the final form of this intervention. After all, this

project aimed to create a lasting and evolving collaborative practice where there was none before, one that would benefit not only the students, but also the teachers.

The research was carried out during normal teaching hours, as a part of a routine revision process. The students were identified based on the subjects they studied (A level mathematics and physics).

Research plan

Firstly, the A-level mathematics and physics specifications (Pearson Edexcel, 2018; Pearson Edexcel, 2020) were compared. Once this step was completed, teachers were able to express their preference for collaboration on overlapping topics and explain their choices. Both of these steps informed RQ1. Before the successive collaboration session, the participating teachers (one mathematics and one physics teacher) designed three revision tasks independently, with clear guidance given. The tasks were the non-collaborative tasks (NCTs). The participating teachers then met to collaboratively design three revision sessions on the overlapping topics. The tasks prepared were the collaborative tasks (CTs). The rationale between behind NCTs and CTs was to help isolate the effects of the collaboration.

The series of three interventions then begun. The students were given either NCTs or CTs at random, which they completed individually. Students were also given questionnaires that, amongst other things, aimed to assess their level of confidence in the topic before and after every revision session. The revision lessons lasted about 45 minutes and involved:

1. [5 mins] an initial questionnaire on perceptions of the overlapping topics, and diagnostic questions on a new topic;

2. [20 mins] NCTs and CTs are given to students at random, which the students will complete individually;

3. [10 mins] a review;

4. [5 mins] a post-revision questionnaire.

The choice for a 45-minute revision session was dictated by timetabling and by the time the teachers were willing to dedicate to this format of revision during the pre-exam period. The students completed the prepared tasks individually, to minimise the teacher and peer effects. The tasks and the sessions also considered student backgrounds (for example, their native tongue) and prior attainment. The number of revision sessions was dictated by time constraints on this project as well as the likelihood of data saturation.

In addition to the questionnaires, the analysis of the responses to tasks, as well as the end of year exams, were used to assess the progress of students. This allowed for comparison of the effects of the tasks, and thus collaboration, answering RQ3, while efforts were made to try and control for teacher effects and peer effects.

Once the intervention sessions were completed, students and teachers were invited to semi-structured interviews and asked about their perceptions of the collaborative revision sessions – whether they thought they were valuable and why, and whether they thought that future students should also have them and why. Teachers were also asked whether they were planning on using the developed resources in the future. This part of the research, as well as some of the responses to the questionnaires, helped answer RQ2.

Data collection

Questionnaires

The questionnaire the teachers completed before the task design sessions (Appendix 1) contained six distinct open-ended questions: (1) asking them to choose overlapping topics to collaborate on, and to justify their choice; (2) to state and explain whether these were the same topics that they though students would benefit the most from revising; (3) to describe what they thought about teacher collaboration; (4) to state what were their experiences (positive and negative) of teacher collaboration; (5) what effect they thought this collaboration could have on them; and (6) what effect they thought this collaboration could have on their students. The teacher questionnaire was developed with the purpose of giving teachers a degree of autonomy over their collaboration as well as offering an opportunity to provide answers without much external pressure.

The questionnaires completed by the students at the beginning of each intervention lesson (Appendix 2) contained one multiple choice question asking about the last time they encountered a particular topic, and one question asking them to rate their level of confidence in a given topic in physics and maths using a Likert scale, along with a justification of their answer. These two questions were followed by five diagnostic multiple-choice questions that were related to the topic being studied. The students also had the option to change their answers to the first two questions after completing the diagnostic questions.

The questionnaires completed by students at the end of each intervention lesson (Appendix 3) contained five questions: (1) a rating of the level of confidence in a given topic in physics and maths using a Likert scale, and a justification of the answer; (2) a

rating of the extent to which students thought that the session was useful in helping them improve their understanding of the topic; (3) a rating of the extent to which they thought this was due to working on both subjects at the same time or due to the tasks that they have completed / reviewed during the lesson; (4) whether they would have preferred to work on this topic separately for maths and physics; and (5) whether they thought that future students would benefit from sessions like the ones they have completed.

Semi-structured interviews

The semi-structure interviews were conducted with the teachers individually, and in small groups with students. For teachers, this was dictated by the timetabling constraints as there were no lessons within the school week where both teachers were available at the same time. As for students, the interviews were conducted in their usual physics groups, at the end of one of their afternoon lessons. This was motivated by the intention to limit any disturbance to their learning and revision.

The semi-structured interviews completed with teachers explored their perceptions on the collaboration, as well as the benefits of the sessions, and possible ways of improvement through the following guiding questions:

1.How do you feel this intervention went?

2.Do you think that your students have benefited from this intervention?

3.Do you think that you have benefited from this intervention?

4.Do you think that these kinds of sessions would be useful in the future?

5.What do you think could be changed or improved?

The semi-structured interviews completed with students explored similar themes through the following guiding questions:

1.What do you think about learning/revising (overlap topics) maths and physics together?

2.Did you feel that those sessions were helpful?

3.What did you like about these sessions?

4.What did you not like about these sessions?

5.Do you think that these kinds of sessions would be useful in the future?

6.What do you think could be changed or improved?

Data analysis

Simple quantitative analysis, focusing mostly on frequencies and distributions, was carried out with Likert scale and multiple-choice responses to the questionnaires. Simultaneously, semi-structured interviews and open-ended responses from the questionnaires were transcribed and analysed for common themes using the qualitative analysis software package NVivo. Student responses to the NCTs and CTs, as well as their physics end-of-year exams were marked and used to evaluate general student attainment/performance in the topics.

The sustainability of this collaboration was evaluated through student and teacher questionnaires and interviews. Both groups were asked about their perceptions of the intervention and whether they thought it should be implemented in the future. Additionally, the collaboration was also be evaluated against metrics such as time required, ease of design and delivery, and the impact on students.

Limitations of this study

One of the limitations to this study was the lack of control over task design effects. It is possible that some of the individually-designed tasks might have been better suited for the learning needs of students, and so any positive or negative effects of the intervention

could be attributed to task design rather than collaboration. In order to address this limitation, teachers were aiming to design and choose tasks against specific points of subject specifications. Both teachers had access to a library of tasks that have been chosen and approved by the Edexcel exam board. Similar teacher experience of both teachers also helped to limit task design effects, as they were less likely to choose or design tasks that would substantially differ in suitability against a specific learning objective.

This study also paid little consideration to the pedagogical content knowledge of the teachers. However, the teachers that were selected for this study came with similar levels of experience (around five years in teaching), similar levels of education (both have completed doctoral degrees), and similar roles held within the school (both have been working at the school for around a year, as subject tutors). This choice of participants hopefully introduced a level of control for pedagogical content knowledge and power dynamics.

The fact that all students had English as their second language was yet another limitation, as ideas and perceptions might have been lost, unexpressed, or misinterpreted. In order to accommodate for this, students were allowed to use translation software, and student were given questions ahead of the semi-structured interviews.

The fact that students were preparing for their end-of-year exams also imposed some limitations. Firstly, it was difficult to differentiate between the effects of the intervention versus the effects of general revision that the students undertook. Secondly, post-intervention analysis of the effects of the study on students was partly based on the final physics exam (which contain questions relevant to the content covered in the revision sessions carried out). It was unethical to ask students to sit an additional form of

assessment when the teachers did not see it as something that would support them with their revision.

Finally, the small sample size (n=10) made it difficult to identify any clear trends, and whatever trends were identified might have been due to random chance. In order to address this the study will focus on the rich, qualitative evaluation of the intervention, rather than a quantitative approach. Additionally, this study is explorative in nature and mainly aims to only inform future interventions.

Ethical considerations

This study received the Oxford University's CUREC approval. During the design, implementation, analysis, and reporting phases of this research project every attempt was made to follow the British Educational Research Association ethical guidelines (BERA, 2018). All student data were anonymised and non-identifiable and were only used for the purpose of this project.

Following the written consent from the headmaster, verbal consent was obtained from the students. No further consent was sought, as the study followed MSc modus operandi. The participants were able to withdraw from the study at any point. They were also informed and reminded about this at the beginning, and throughout the study.

Even though the nature of the questions were not sensitive, when interviewing participants, I made every effort to make participants feel free from judgement and respected. I made sure that they understood that any responses they provided were non-identifiable.

The fact that I am a teacher, and that the intervention was conducted with and under the supervision of a teacher, was a factor that will influence this study. Effort was taken to assure that the effects of this power dynamic and the teacher influence were

minimised as much as possible, through task design (students completed work individually) and by ensuring students about the anonymous nature of this study. The students were informed that the study focuses on the effects on collaboration and was not a test of their views or performance. Responses collected during the interviews (which were conducted in a familiar classroom) were read back to students to confirm that they approved the responses collected, with the students fully aware that they could withdraw from the study at any point.

The school hosted students from different countries, religions, backgrounds, and cultures, and as a result this research might have also been influenced by cultural differences. However, the students knew each other which minimised burdens associated with working with people that they are unacquainted with.

The semi-structured interviews were conducted in-person. In order to ensure that participants felt comfortable, prior to the interviews I reviewed the basic aspects of the research project with participants and the process of the interview itself. I made sure that they could ask any questions they may have had.

Additionally, in order to address possible power dynamic issues between the teachers, the tasks that were designed had equal share of marks for both subjects, and the design sessions were kept focused and lasted less than one hour.

This study prevented potential burdens for participating teachers (such as, increased workload), by making participation voluntary, limited to one session, within their usual teaching hours, and with the teachers able to withdraw at any point.

Finally, since the study took part during normal teaching hours, there was a potential risk to the loss of classroom time which might have had a negative effect on students' learning. To address this issue, this intervention took form of revision sessions

that were normally conducted at that time of year, as a part of preparation for the end-of-year exams. This meant that any changes to the schemes of work were minimised.

Findings

RQ1 Which mathematics and physics overlapping topics do teachers want to collaborate on and why?

Overlapping topics

The school where the study was undertaken implements a disciplinary subject structure and uses the specifications prepared by Pearson Edexcel to deliver A-level physics (Pearson Edexcel, 2018) and mathematics (Pearson Edexcel, 2020). Comparing the mathematics and physics specifications reveals that both disciplines share numerous concepts (such as vectors, exponentials, logarithms, trigonometry), but often use them in different contexts and to different levels of complexity. For example, both subjects teach vectors and require their students to use them in two dimensions, deal with magnitudes and directions, and carry out addition of vectors (triangle and parallelogram laws and apply them in context). Physics, however, also asks students to work with and distinguish between scalar and vector quantities, whereas mathematics instead requires competence in using vectors in three dimensions, vector and scalar multiplication, working with position vectors, using vectors in pure mathematics problems, and familiarity with vector notation. In this particular example, it is clear that the mathematics expectations for this topic are much more extensive than for physics.

The topic where the two disciplines overlap the most is mechanics. It is a stand-alone unit within the physics specification, and a sub-topic of the statistics and mechanics unit in the mathematics specification. Although specifications do not overlap exactly, and

do not phrase their expectations in the same way, the exam questions that test the corresponding specification points bear a resemblance that is significant enough to label mechanics as an overlapping topic.

Considering what Wong and Dillion (2020) said about the importance of finding suitable points of connection between the subjects on collaboration, mechanics was broadly chosen as a topic for teachers to collaborate on. Having identified this point of connection, the teachers were then asked to agree on which points within their specifications they wanted to work together on. By completing a questionnaire, both teachers have selected kinematics, Newton's laws of motion (dynamics), and moments as the three sub-topics. The details of the subject specifications on these can be found in Appendix 4. The teachers have made their choices based on "considerable overlap between the two specifications with some small but significant differences in emphasis, technique and values" (physics teacher). It is worth noting that, to some extent, teachers' personal preferences and areas expertise influenced their choice of topic. For example, one of the teachers did not find moments to be a very enjoyable part of the curriculum to deliver but thought that through collaboration his perception might change or evolve. Both teachers also believed that these were the sub-topics that students would benefit from revising the most. Finally, these topics satisfy the three criteria that themes must meet in order for a collaborative effort to be effective (Williams et al., 2016). They are all relevant for both subjects, they can support learning through shared content in both disciplines, and help students apply their knowledge outside of mathematics and physics.

Differences within the overlapping topics

When considering the differences between the three chosen sub-topics (kinematics, Newton's laws of motion (dynamics), and moments) from the point of view of mathematics and physics specifications, both teachers noted that the subjects share many core ideas, key words, equations, and themes within those sub-topics. However, teachers also noticed that the topics differ in focus, expectations, and the way questions are presented. These perceptions emerged during their collaborative session, where the teachers discussed the way problems are presented in their respective subjects. Both observed that mathematics questions usually do not include any diagrams and consist of text and numbers only, whereas physics questions usually include pictures and a real-life context.

> *Mathematics teacher:* "(…) there's no scenario, context that [mathematics questions are] given in, so the [students] find it always quite difficult to picture it. In other words, [physics] seems to have (…) really detailed scenarios. This is the Moon landing. (…) Here's a springboard. So that's kind of cool, and that's something that I wish they did more often in maths."

This particular difference can be linked to the different overarching themes and learning objectives within the subject specifications. Mechanics in the mathematics subject specification is guided by the effort to help students "understand, interpret and extract information from diagrams and construct mathematical diagrams to solve problems" (Pearson Edexcel, 2020, p.9). Physics on the other hand, is led by the expectations where students should "demonstrate and apply the knowledge, understanding and skills described in the content" and "develop (…) ability to apply mathematical skills to physics" (Pearson Edexcel, 2018, p.5).

This example shows that even though mathematics and physics share content, there are considerable differences within that need to be recognised. Apart from the lack of diagrams in mathematics questions, some of the other differences within the overlapping content include physics paying little attention to modelling assumptions that are made in mechanics, the way SUVAT equations are derived, and the value for the acceleration due to gravity on Earth that is used in calculations. In mathematics, students are often asked to state assumptions made in answering questions (for example, they might have to state whether they are assuming that an object is treated as a particle, a rod, or a uniform body). In terms of deriving equations of motions, in physics students derive them using algebraic and graphical methods, but in mathematics they also use calculus. Finally, in mathematics, the default value for gravitational acceleration to be used by students is 9.8 m s^{-2} (although some questions specify it as 10 m s^{-2}, or algebraically as g), whereas in physics the value is always 9.81 m s^{-2}. The roots of these differences can all be linked to particular points within subject specifications.

Redish and Kuo (2015) suggested that studying mathematics and physics is like studying two distinct, albeit similar languages: that the overlaps can support the learning of the areas where they differ. This opinion was also held by the mathematics teacher who said that:

> *Mathematics teacher:* "(…) you can teach [students] the root basics [of mathematics and physics], like say for example: you know all Roman languages have the same root basics, which is Latin, so you can teach them the root basics, and then you can show them the different branches. It's like, so this is the common language between (…) maths and physics and this is how this particular topic differs in maths. This is how it differs in physics, and the questions will look like this, and you have to answer them in this way."

This is important for understanding why teachers prefer to collaborate on some topics more than others. Finding the points of connection is vital for enabling collaboration (Wong & Dillion, 2020), however identifying and addressing the differences withing the overlapping topics is what can make interdepartmental collaboration worthwhile. The supporting evidence for this came from the interviews. Through this project, both teachers have developed their interdisciplinary pedagogical content knowledge (one of the limiting factors to effective collaboration as identified by Weinberg and Sample McMeeking (2017)) and both said that learning from one another is something that they valued and appreciated in this collaborative effort. This will be discussed in more detail later.

RQ2 What do students and teachers think about collaborative revision for A-level mathematics and physics?

Analysis of interviews and open-ended questionnaire questions revealed a number of themes and ideas that students and teachers hold about collaborative revision for A-level mathematics and physics. These themes broadly revolved around the potential benefits that interdepartmental collaboration might bring, such as improved teaching and competence, and the barriers to either collaboration itself, or to enabling those benefits.

Perceptions of the benefits of interdepartmental collaboration

In general, the students and the teachers came into this project with mainly positive perceptions on interdepartmental collaboration. The students have shared their views without having previously experienced such form of collaboration, whereas teachers based their opinions on limited (albeit positive in the case of the mathematics teacher) experience of working with teachers from other departments.

Interdepartmental collaboration is something that the majority of students perceived to be valuable and potentially beneficial. Seven out of the ten students that took part in this intervention clearly identified one or two possible benefits. The most common one was the improved understanding of both subjects and the topics covered. This was noted by four students, with one attributing this benefit to shared similarities between the mathematics and physics syllabuses. Another four students also recognised the value of additional practice in answering exam-style questions, especially for concepts that relate to every-day life.

> *Student 4:* "There are many similarities. Practicing answering questions helps understanding."
>
> *Student 5:* "(..) revising this topic, [mechanics], is very useful, [as] we can use it everywhere, (…) [it] is very common in life."
>
> *Student 9:* "(..) looking at the same aspects of different curricula is beneficial. It improves understanding."

Apart from an improved understanding, two students also noted that collaboration can save time, and one that it can also save energy, as a result of studying two subjects at the same time.

Having talked about these benefits it is also important to note that some students put forward some disadvantages too: one student thought that collaboration might benefit mathematics more than physics, while another student suggested that only those studying both subjects might see some gains.

> *Student 1:* "I think that it can help maths more than physics. Physics is more about understanding the concepts, and collaboration [with] maths might not always be beneficial to physics."
>
> *Student 5:* "I think that learning and revising those subjects separately is better, as only students who do both subjects can benefit."

The first statement is particularly interesting and in contrast with what Wong and Dillon (2019) claim about the asymmetric benefit between mathematics and physics. This could suggest that this asymmetric dependency might be lost or even inverted when considered in some contexts, such as mechanics.

Similarly to what the students thought, both teachers also recognised the potential of interdepartmental collaboration to improve attainment and competence, even though "the link between maths and science [at the school] is not an existing base" (physics teacher). The physics teacher has argued that due to "some small but significant differences in emphasis, technique, and values" within the overlapping topics that can "cause confusion", the collaboration between teachers can "help [students with] their level of understanding by improving clarity". This could be achieved by providing an opportunity to see concepts and topics from a different angle. On top of that, regular collaborative sessions could help students recognise patterns more often and develop a habit of making links between the disciplines and thereby improving transfer of knowledge between mathematics and physics. Likewise, the mathematics teacher has also noted that collaboratively prepared revision sessions can assure a different revision format, an alternative to the subject specific past-paper practice, that can help students "see how topics overlap between subjects and (...) that what they learn is part of their holistic education".

The teachers have also considered the possible ways in which working together may impact them as educators. The physics teacher agreed that "it is always helpful to learn from others, but [that] this also takes time from the working day", and that it could "broaden their [own] knowledge [and] improve teaching skills". The mathematics teacher expected to learn new "new techniques" that could help him support students better

unless the collaboration was forced and applied to something that does not require collaboration.

Next, the teachers have recognised that even though collaborative efforts might require an initial investment of time and effort, they might lead to conservation of time and effort in the long term. This could be a result of either developing quality resources that would be re-used in the future, or by coordinating teaching.

> *Mathematics teacher:* "(…) we've wasted time over this year teaching the same topic. (…) Why not have combined lessons? Physics and maths on particular topics? (…) If both subjects are teaching, (…) [for example] Newton's laws of motion, why can't they happen together?"

Moreover, one of the teachers has raised a point that teaching their subject of expertise is what they want on a daily basis and that collaboration, although welcome, should not take up too much time and space and should not be the focus of their teaching.

> *Physics teacher:* "If you're given time to prepare, then yeah, OK, you can do it, but I wouldn't want do it, for more than the lesson or two, because I'd want to teach the physics, not maths."

In other words, although interdepartmental collaboration holds potential merits and benefits, it cannot replace, at least in the given context, quality and subject specific teaching. This observation provides an additional angle to teachers' lack of confidence beyond their own field of expertise, one of the factors to effective interdisciplinary action (as considered by Weinberg and Sample McMeeking (2017)): that it is the personal preferences, and not how comfortable the teachers are in teaching other subjects, that can be the obstacle to collaboration.

Lastly, one teacher expressed reservations about the extent to which they thought the benefits from collaboration may be significant enough to justify the efforts, and whether these efforts target the right area of the curriculum.

> *Physics teacher:* "It's a marginal benefit, I think. (…) Another way of looking at it is, is it the most difficult thing that physics students or math students face? Is this particular topic, mechanics, is it the most difficult? So how much is there to be gained from doing it?"

This is a vital question to consider, as the extent and the kind of benefits observed will be the decisive factor for whether this kind of collaboration will be likely to take place again, in this form or another. In other words, will this collaboration be sustainable? This issue will be explored later, as firstly, barriers to and for collaboration will be considered.

Barriers to and for collaboration

Having looked at the perceptions that students and teachers hold on the benefits and the barriers to collaboration, the next questions that arise are: how did the students and teachers find the revision sessions, and what improvements did they suggest? Overall, everyone had positive opinions about the intervention with many ideas for improvements being put forward.

The ideas of barriers, which came almost exclusively from the teachers, fell into two categories: barriers to collaboration and barriers for collaboration. Barriers to collaboration are those obstacles that make it difficult for teachers to work together (for example, lack of support or time constraints). Barriers for collaboration on the other hand, are hindrances that a collaborative effort might want to address and overcome. For example, in the case of interdepartmental collaboration, it might be a common

misconception, or a shared struggle, that the teachers might want to support their students with.

Barriers to collaboration revolved around workload, time, students, space, guidance, and support, and most of them reflected closely what researchers say about the factors that inhibit collaboration (see for example, Vangrieken et al. (2015)). Firstly, workload (the current level of responsibilities and commitments of the teachers) presents a barrier in multiple ways and is strongly related to time. Teaching a full timetable, that can feel "too tight", on top of other responsibilities, such as marking and lesson preparation, made the teachers feel "cut to the bone". Additionally, the effort and the time required to plan and then implement the revision sessions posed another obstacle. In light of that, finding a dedicated timeslot during which to collaborate is not easy.

The themes of support and resources are somewhat linked to the previous ones and show how the structure and the setting of the school may inhibit collaborative efforts. If the teachers do not have the time to collaborate, and if there is little flexibility with either freeing up the time or modifying the timetable in such a way that could support teachers to work together, co-teach, or implement an intervention, then it is unlikely that collaboration will take place. For example, if the teachers wanted to co-teach a particular topic, then the inability to change when the specific topics are taught during the academic year will inhibit such efforts. What is more, in order to justify a collaborative revision session, the teachers pointed out the essential need for classes to be comprised of students that do both, mathematics and physics, which is not always the case.

> *Physics teacher:* "(…) there's not a lot of flexibility in terms of use of resources. (…) I don't feel like I could do any more work."

> *Mathematics teacher:* "Schools don't always allow or give space for teachers to collaborate. The timetables are too tight, there is lack of support."

For collaboration to take place, appropriate support also needs to be provided, one that does not simply give a green light, but actively addresses the needs and the demands of what those involved may require. Finally, the teachers mentioned that there is very little clear guidance on how to establish collaborative practices, and with limited experience it is not an easy thing to implement.

Having discussed barriers to collaboration, we now turn to the barriers for collaboration, those that the teachers could address through the intervention, and that the students identify as areas that they would like to work on. The barriers identified by the teachers were linked to mathematical skills, making/stating assumptions, language, and diagrams.

> *Mathematics teacher: "*(…) if English is not their first language, they really struggle. (…) [for example, Student 5] really struggles in understanding the word, or the words, and transferring them into a picture to then solve a question. He can do the math, but he doesn't understand 90% of the words in context."

Knowledge of keywords, and the level of English, were identified as significant barriers to students' success in mathematics and physics. Students often find writing explanations and answering written-response questions difficult due to the language barrier. These students often have the mathematical ability to solve problems but cannot access them because of language or the inability to translate a word problem into a diagram. Written response questions especially posed a significant challenge to students, as well as questions that ask require a description or an explanation. Finally, teachers and students have acknowledged that although mathematics and physics have many things in

common (like some of the key words, and the way questions are structured), they also differ significantly. Each subject has a different point of focus, meaning that how students perceive mathematics and physics and how they express themselves in each discipline is not the same, as if these were two different languages (as already suggested by Redish and Kuo (2015). As a result of these consideration, the teachers decided to design tasks that focused on these two areas: written response questions (stating assumptions) and producing diagrams.

Thoughts on the revision sessions

Most of the students and teachers thought that the sessions were useful to different extents and for various reasons. For students, "they provided an opportunity for extra revision and looking at material from different perspectives" (Student 7). Additionally, the teachers reported that they felt that this collaboration has been beneficial not only for their students but also for their professional development.

All students have found the sessions to be useful to some degree, as their rating of the usefulness of the sessions ranged from somewhat useful to very useful. There were seven instances of the students finding the sessions very useful, 10 fairly useful, and 12 somewhat useful. This finding alone could provide the reason to run similar revision sessions in the future. However, it is possible that the students felt inclined to say that the sessions were useful, or that there is an alternative format of revision that could be more useful. Having observed the positive reception of these sessions by the students, is there evidence there to suggest that teachers prepare tasks collaboratively?

The findings presented in the breakdown of frequencies by task (CT and NCT) in Table 2 (with the full table of results in Appendix 5) are in favour of CTs. Altogether, 10 students found CTs to be fairly or very useful as opposed to seven students for NCTs. This

margin is not very big and may be due to random chance but given the benefit of collaboration sessions on teachers' professional development (discussed later) there is a strong basis to recommend teachers to collaborate. Breaking down the results by topic as well as by the task type (Table 3) showed no clear trends, with similar number of students finding the sessions useful to varying degrees.

Usefulness of the session	**CT**	**NCT**
Very useful	3	4
Fairly useful	7	3
Somewhat useful	4	8

Table 2. Usefulness of the sessions according to the type of task (CT or NCT).

Task type	**Very useful**	**Fairly useful**	**Somewhat useful**	**Grand Total**
NCT	**4**	**3**	**8**	**15**
SUVAT	1	2	2	5
Newton's Laws	1	1	3	5
Moments	2		3	5
CT	**3**	**7**	**4**	**14**
SUVAT	1	1	2	4
Newton's Laws	2	3		5
Moments		3	2	5
Grand Total	**7**	**10**	**12**	**29**

Table 3. Usefulness of the session overall by task type.

Further analysis on a student-by-student basis showed that more students thought that the usefulness of the session came from the task that they have completed and reviewed during the lesson (two very large extent, 13 large extent, 13 neutral, one little extent), rather than from working on both subjects at the same time (two very large

extent, 10 large extent, 16 neutral, one little extent). Interestingly, four students have reported finding the sessions not very useful during the group interview, in contrast to their initial responses to the questionnaire. This might have been due to the time the students had to think about the sessions (the interviews were held the day after the intervention cycles have finished) or because they had ideas for how to make these sessions better, deeming the ones they have received as less useful.

Even though most have found the sessions useful, one student raised a concern that the sessions can be potentially beneficial but that these sessions might be more beneficial to maths more than physics. This echoes what Student 1 said about this matter earlier, and contrasts with what Wong and Dillon (2019), as well as other researchers, have said about the asymmetric benefit between mathematics and physics.

> *Student 5:* "These sessions can be useful. However, this might not be fair to physics, since maths is more numerical, and physics requires more explanations and understanding of concepts, maths can help physics. This means that someone who understands physics better will probably do better in maths, but someone who does better in maths won't necessarily do better in physics."

Overall, all of the students have agreed that these kinds of sessions would be useful for future students and that they should be repeated. With this, many students have suggested improvements, which are discussed later in this paper.

Teachers have also expressed positive views about the collaboration, saying that the students have found them useful, that they had a positive impact on their understanding of the other subject, and that they were beneficial for their own professional development. However, these views can carry a certain degree of bias, as the

teachers have come into this intervention with positive attitudes and based their opinions only on their own perceptions.

> *Mathematics teacher:* "Overall, I think that this collaborative effort was good and specific."
>
> *Physics teacher:* "Well, yes, it reminded me about the math side of things… On the assumptions that we make in physics that aren't explicit."

It is important to note that the physics teacher mentioned that they did not see a strong incentive to collaborate more, arguing that potential benefits may not be worth the necessary effort needed to establish collaborative practices. Even though the students and the teachers found the sessions useful and beneficial, there were many ways in which they thought these sessions could be improved in the future. These will be discussed next.

Suggested improvements

Students and teachers have proposed a number of ways in which collaborative (revision) sessions could be implemented and improved in the future. These improvements revolved around the focus of the sessions as well as the collaborative process itself, and the support system around it.

Students said that they would like to see a wider range of questions on mathematics and physics, that progress in level of difficulty. They could be less or more closely related, but ultimately provide more opportunity for mastering concepts and making connections. Some students also would like to see more explanation questions.

The teachers have suggested that a collaborative approach could be implemented in delivering, rather than revising, of mechanics and that teaching responsibilities could

be shared between the teachers. This could potentially result in a faster and more effective teaching of this topic.

> *Physics teacher:* "(…) why not have math teachers teach mechanics in physics and why not have us teaching mechanics in maths? (…) we'd have to go over the topic from the other subject's perspective. Or just switch. You know you could switch one or two lessons?"

For the overlapping topics, coordinating teaching could mean making the whole teaching process as efficient as possible, so that the respective mathematics and physics lessons supplement and relate to each other, and not deliver similar content twice. Gained time could then be used for teaching other topics or for revision. However, it has been noted by the teachers that this might not work as "not everyone who does mathematics, does physics" and that the timetable for the students would have to align with the timetable of the teachers.

Another suggestion pointed out that future revision sessions should be more varied and involve a wider range of activities. The physics teacher has reported that the students have become tired of the format of the revision sessions. The same teacher also suggested that the teachers could swap, so that the mathematics teachers teach mechanics in physics and the physics teachers teach mechanics in mathematics.

Both teachers also agreed that there should be dedicated time during the week for collaboration. This time however should be taken from the lesson allocation, so that no additional workload is added to the teaching staff. This would require support from the leadership teach and would have to be reflected in the timetables of all the ones involved.

> *Physics teacher:* "Giving one free lesson to prepare. (…) I wouldn't mind [collaborating next year again] (…) but not if I don't get the time to prepare."
>
> *Mathematics teacher:* "I think that the way to capitalise on this would be to have an allocate time for our curriculum area to collaborate."

It has also been proposed that collaborative sessions should not be singular events but should run throughout the year to help students make connections and recognise patterns and links between the disciplines. In other words, those sessions should focus on enabling the transfer of knowledge between the disciplines.

> *Mathematics teacher:* "(…) I think that it should be year wide, rather than just those specific time periods, because then the kids are like 'Oh, that's just revision'. Whereas if you talk about collaboration throughout the whole (…) syllabus then they can start seeing patterns between the two subjects as opposed to just seeing microcosms [of unconnected content]. I think it (…) needs to be curriculum planning."

Finally, in order to support collaboration, both subject groups should involve a larger number of people and also look at teaching mechanics (and other overlapping topics) rather than just revising it. In order to accommodate that, they could agree on when to jointly deliver this topic and consider things like division of the syllabus and sequencing.

RQ3 What effect does collaborative planning for revision of overlapping topics in A-level mathematics and physics have on students and teachers?

The effects of this project, which involved a collaborative design session and three revision lessons, can be deduced from the conversations held with the students and the teachers, and from the questionnaires completed. Please also note, that due to an absence Student 6 has only completed the tasks on Newton's laws and moments, and not

on SUVAT. Although this student has completed the missed task in their own time after the revision lesson, their responses to the questionnaire were not included in the analysis as they have not completed it in the same environment as the other students. It has been decided however that the other responses to questionnaires, as well as their views on collaboration, held validity and should be included in the analysis.

Although the perceptions on the collaboration were generally positive, and the participants involved had an optimistic outlook on the future of such collaborations, the evidence on the effect of the intervention on students' confidence and attainment has been found to be very weak, and not enough to solely support recommending this type of collaboration in the future.

Perceptions of the effects of the revision sessions

As discussed under RQ2, the students found the sessions to be generally useful, which was also reflected in the perceptions held by the teachers. Both teachers thought that students' understanding of the revised topics have improved as a result of these revision sessions.

> *Physics teacher:* "They definitely improved because of the exercise. There's no doubt. It made them think about it."

The intervention helped teachers learn about the other subject and adjust their teaching to accommodate their points of focus (for example, the physics teacher has made the effort to explore assumptions that they make in mathematics). As a result, teachers' general knowledge has improved as well, meaning that the collaborative sessions provided an opportunity for the teachers' continuous professional development.

Physics teacher: "Well, yes, it reminded me about the math side of things… On the assumptions that we make in physics that aren't explicit. (…) From the physics side, it helped me understand the assumptions that were being made as well."

Mathematics teacher: "I think that I benefited from the intervention by learning about physics. I especially valued learning from the other teacher and by learning about the different kinds of questions that you guys ask in physics. For example, teaching moments collaboratively, a topic that I don't like, I thought it was useful for me to discuss (…). I think however that this sort of collaboration could support teaching of these overlap topics, rather than revising them. It would have to work for both teachers or departments, but in theory that could speed up the teaching process and free up time for revision or consolidation, or just finishing the material early."

Levels of confidence

The results from the questionnaires have been analysed from various perspectives in terms of shifts in confidence in mathematics and physics. Overall, there were 19 instances of positive shifts in confidence, 31 neutral ones, and eight negative ones (Table 4. Confidence shifts by subject. Mathematics has observed fewer positive shifts than physics (seven compared to 12), but also fewer negative shifts in confidence (three compared to five). Within these results, CTs had four positive, one negative, and nine neutral shifts in mathematics, and four positive, three negative, and seven neutral shifts in confidence in physics. NCTs on the other hand, resulted in three positive, two negative, and 10 neutral shifts in mathematics, and in eight positive, two negative, and five neutral shifts in confidence in physics.

Task type	**Mathematics**			**Physics**		
	Positive	**Neutral**	**Negative**	**Positive**	**Neutral**	**Negative**
NCT	3	10	2	8	5	2
CT	4	9	1	4	7	3
Total	7	19	3	12	12	5

Table 4. Confidence shifts by subject.

There is little evidence to suggest that CTs affect students differently than NCTs in mathematics, however that is not the case if the findings are analysed by subject. For physics, NCTs have resulted in twice as many positive shifts compared to CTs (eight versus four), and one less negative shift. This is difficult to generalise due to the small sample size, but it does indicate that the teachers do not have to collaborate together for the students to benefit, or bear the negative consequences, of such intervention. For the complete table of results for confidence shifts in physics and mathematics, see Appendix 6.

Further breakdown of the shifts in confidence by task offers additional insight into the effects of this intervention (**Error! Reference source not found.** and Figure 5). SUVAT tasks had the least significant effect on students, with two positive shifts in confidence and one negative in physics (NCTs in both cases), and neutral otherwise. Moments tasks, on the other hand, resulted in the greatest number of positive shifts (five in mathematics and five in physics) but also the greatest number of negative shifts (one in mathematics and three in physics). As discussed later, the question on moments was the one that was most successfully answered in the post-intervention physics assessment, which could hint that collaborative revision could especially benefit the consolidation of this particular topic.

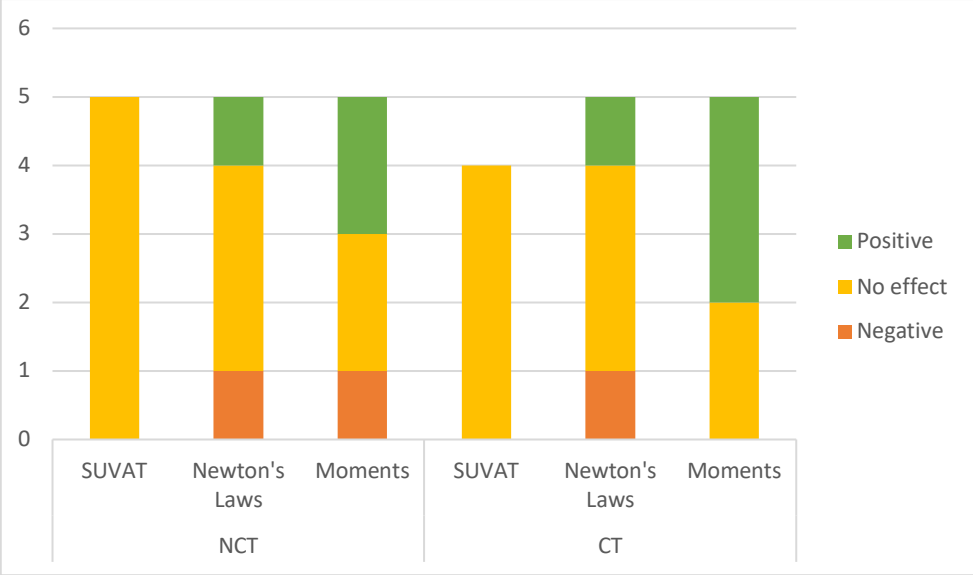


Figure 4. Confidence shifts in mathematics by task type and by topic.

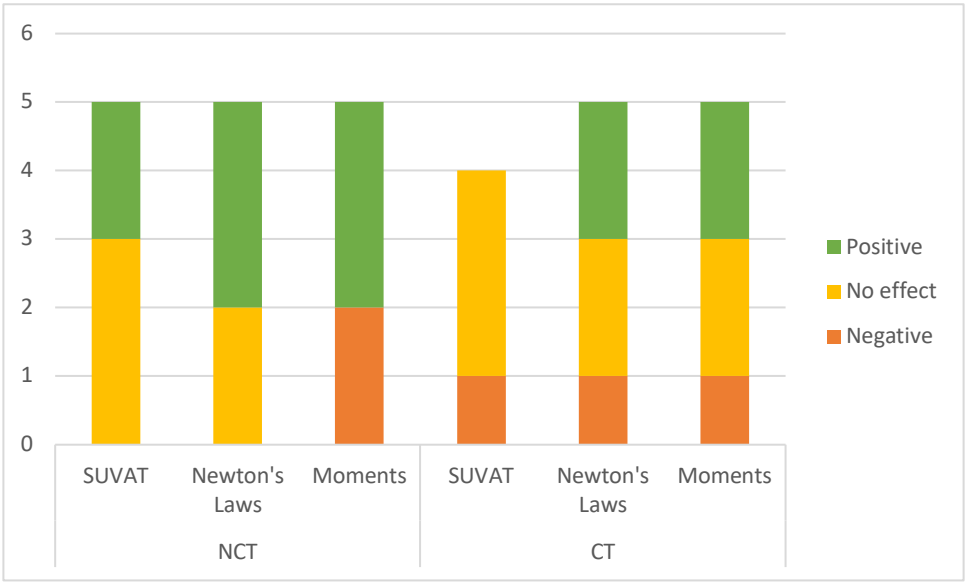


Figure 5. Confidence shifts in physics by task type and by topic.

Considering the time since last encounter of the topic allows for a number of observations to be made. Analysing the findings presented in Table 5 and Table 6 shows that students who encountered a given topic within a week before the intervention reported higher initial levels of confidence in mathematics (four very confident, and seven fairly confident) and physics (two very confident, six fairly confident, and three somewhat

confident), compared to students who have encountered the topic within the last month, more than a month ago, or longer.

Last time a topic was seen (mathematics)	**Slightly confident**	**Somewhat confident**	**Fairly confident**	**Very confident**	**Total**
(A) This past week			7	4	11
(B) Within the last month		5	4		9
(C) More than a month ago		2	1		3
(D) More than 3 months ago	2	3	1		6
Total	**2**	**10**	**13**	**4**	**29**

Table 5. Initial levels of confidence in mathematics by time since a topic was last seen.

Last time a topic was seen (physics)	**Slightly confident**	**Somewhat confident**	**Fairly confident**	**Very confident**	**Total**
(A) This past week		3	6	2	11
(B) Within the last month		5	3	1	9
(C) More than a month ago		3			3
(D) More than 3 months ago		5	1		6
Total	**0**	**16**	**10**	**3**	**29**

Table 6. Initial levels of confidence in physics by time since a topic was last seen.

Additionally, Figure 6 and Figure 7 show that these students have also seen fewer positive shifts in confidence levels in mathematics (one positive, eight neutral, two negative) than in physics (five positive, four neutral, two negative). Further analysis on an individual basis also found that the same students perceived the sessions as moderately useful (one very useful, four fairly useful, and six somewhat useful), valuing the opportunity to work on both subjects at the same time, and to engage with the given tasks, evenly, but not to a very large extent.

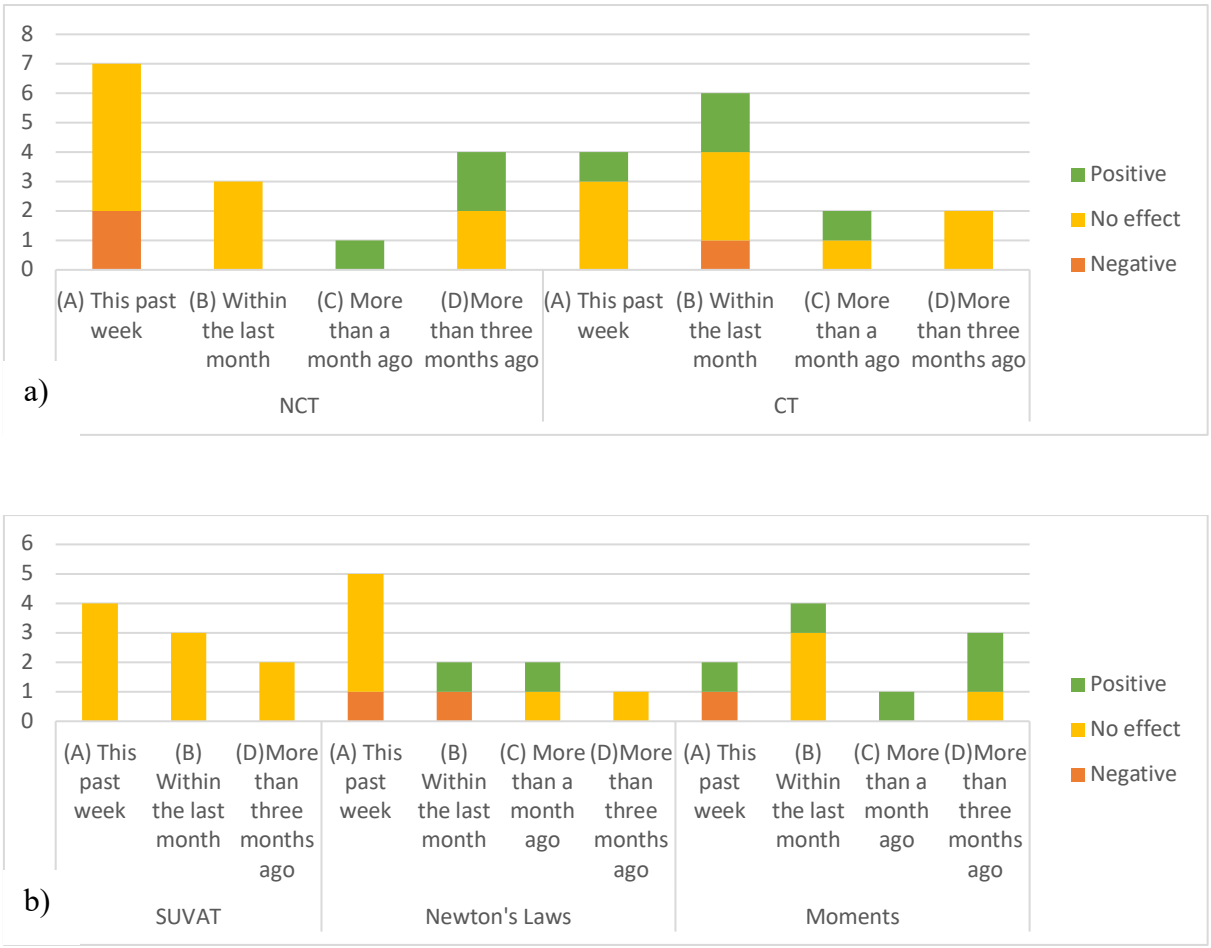


Figure 6. Confidence shifts in mathematics by time since last encounter of the topic by a) task type; b) by topic.



Figure 7. Confidence shifts in physics by time since last encounter of the topic by a) task type; b) by topic.

The instances where students have encountered a given topic within a month before the intervention have seen more positive shift in confidence levels in mathematics (two positive, six neutral, one negative) but less in physics (two positive, four no effect, three negative). These students also found the sessions moderately useful (two very useful, three fairly useful, four somewhat useful), seeing equal value in the opportunity to work on both subjects at the same time, and to engage with the given tasks, but not to a very large extent.

The instances where students who have encountered a given topic more than a month ago or more (nine) reported the lowest levels initial levels of confidence in mathematics and physics. These students have also seen the most positive shift in confidence levels in mathematics (four positive and five neutral) and in physics (five

positive and four neutral) with no negative shifts. This can be seen in Figure 6 and Figure 7. Further analysis on an individual basis also showed that these students also found the sessions most useful (four very useful, one fairly useful, and two somewhat useful), valuing the opportunity to work on both subjects at the same time, and to engage with the given tasks, evenly. All of these observations unfortunately do not offer any clear trends, which might be due to a small sample size.

Analysis of the tasks and tests

In general, the students have completed the tasks with no or little assistance and have made good use of the marking schemes provided. The full table with comments on students' completion of NCTs and CTs can be found in Appendix 7. There were five instances of task completion with little assistance, 18 instances of students struggling with an open response question, four instances of students needing assistance with deriving equations of motion, and four instances of students needing assistance with a calculation question in mathematics and five in physics. The high number of students struggling with open response questions highlights the language barrier that was identified when answering RQ2.

Although the students have obtained a wide range of grades in their post-intervention physics assessment (grades U-fail to A, Table 7), the analysis of tasks that assessed the understanding of SUVAT, Newton's laws of motion, and moments, showed that the question on moments was the most successfully answered one (all students scored 100%, or 2/2 points), followed by SUVAT (an average of 60%, or 3.6/6 points), and Newton's laws of motion (also an average of 60%, or 2.4/4 points).

Student	Prior attainment (Maths)	Prior attainment (Physics)	Post-intervention assessment (Physics)
1	Middle	High	70% / A
2	Middle	High	53% / A
3	Middle	Middle	36% / C
4	Middle	Low	38% / C
5	Low	Low	19% / U
7	High	High	63% / A
8	Middle	Middle	86% / A
9	Middle	Middle	58% / A
10	Middle	Middle	64% / A

Table 7. Grades in post-intervention assessment for physics by student and prior attainment.

Even though the questions carry different weights and are therefore difficult to compare directly, a closer investigation into where the students have lost most marks allows for a number of observations to be made. Three students who have lost marks in the SUVAT question have done so because of the language barrier. They have either not realised that they can apply equations of motion in that context, or they have missed an important piece of information that was contained in the text. For the question on Newton's laws of motion, there was only one instance that would indicate a language barrier, and for the rest of the students, marks were mostly lost due to an insufficient level of detail in their responses (six instances). The other way in which students have lost marks was mathematical in nature - an improper application of trigonometry and SUVAT equations. For a full breakdown of the tasks with comments, please see Appendix 8.

It would be tempting to say that the collaborative sessions had a positive impact on students' answers to the question on moments (given that this topic, together with Newton's laws of motion, observed the greatest number of positive shifts in levels of confidence in physics), however the impact of the collaborative revision sessions is difficult to assess for a number of reasons. Firstly, only the physics assessment has been included in the analysis. Secondly, the assessment questions were chosen independently, without considering the needs of this intervention, and therefore they did not perfectly correspond to the type of questions the students have answered. Next, it is impossible to separate the effects of this intervention from the effects of any previous teaching or revision. Finally, the language barrier posed an obstacle for many students to answering the SUVAT question, making it difficult to assess a level of understanding of a particular topic.

Despite all of the challenges mentioned above, one case hints at a positive impact of the revision session. Student 10, who came in with middle prior attainment in physics and mathematics, who scored three out of five points in the multiple-choice short test at the beginning of the SUVAT revision lesson, and who reported a positive shift in the level of confidence in that topic, has scored full marks in the SUVAT question in the post-intervention assessment. This student's response to the NCT and the assessment question can be found in Appendix 9. Even though this does not prove that collaborative revision could be preferred over any other type of revision, it does suggest that an intervention like this could be an effective and practical part of a more extensive revision program.

Discussion, conclusions and implications

Motivated by the review of the relevant literature, this practitioner research project conducted an explorative investigation looking to establish a co-planning interdepartmental collaboration for revision of mathematics and physics in an independent sixth form college in England. This effort incorporated the terminology suggested by Vangrieken et al. (2015) and the interdisciplinary activity theory proposed by Williams et al. (2016) to evaluate collaboration that a) compared the overlaps between the mathematics and physics curricula; b) had two teachers design revision sessions on overlapping topics in mathematics and physics; c) carried out the revision sessions and evaluated them using teacher and student questionnaires, semi-structured interviews, as well as student work. Three research questions emerged from these aims: RQ1: Which mathematics and physics overlapping topics do teachers want to collaborate on and why? RQ2: What do students and teachers think about collaborative revision for A-level mathematics and physics? RQ3: What effect does collaborative planning for revision of overlapping topics in A-level mathematics and physics have on students and teachers? While acknowledging the special connection between mathematics and physics (Redish & Kuo, 2015), the first research question linked to Wong and Dillion's (2020) call for finding suitable points of connection between the subjects. It also appreciated that understanding teachers' beliefs about collaboration is important for effective implementation of STEM strategies (Margot & Kettler, 2019). The second research question aimed to explore the ideas that students and teachers hold about a collaborative approach to mathematics and science, aiming to bridge the gap in research on student perceptions on teacher collaboration. Additionally, this research question hoped to gather ideas that would inform future collaborations at the school. Finally, the third

research question tried to determine the effects of this collaboration on students and teachers.

For the intervention, two teachers prepared resources on three overlapping topics, first independently and then collaboratively. The collaboration consisted of a task-design session, and a follow-up discussion. Subsequently, the intervention was comprised of three revision lessons, as well as the exploration of the effectiveness of the collaboration through questionnaires completed by students and teachers, and task analysis. Additionally, semi-structured interviews were used to investigate student and teacher perceptions of collaboration, and assessment analysis was used to evaluate student progress.

A number of conclusions and observations can be made by considering all of the perceptions from students and teachers, and the analysis of questionnaires, tasks, and tests. For RQ1, mathematics and physics teacher were most interested in collaborating on the topic of mechanics due to a considerable overlap of content. This satisfies Wong and Dillion's (2020) call for finding suitable points of connection. Considering this overlap of content, it is true that the transfer of knowledge might either be enabled or hindered, and this is where teachers can learn from each other and find a way of supporting their students in the process of learning. If the topics were completely different then there would be no points of contact to collaborate on, and if the topics were identical then although there would be a scope for collaboration, it would not be an interdepartmental one. For RQ2, students and teachers find collaborative revision useful, providing a strong incentive to continue implementing, as well as recommending, a similar kind of practice in the future. Such recommendation is based on the following pieces of evidence: (1) mostly positive perception of the usefulness of such sessions by the students; (2)

teachers' positive perception of the impact on the intervention on their own subject knowledge and teaching. Moreover, collaborative revision can be effective "unless you are forced to collaborate on something that doesn't require collaboration" (mathematics teacher). Collaboration also requires a shared goal and support, which can take the form of available resources, or help from other staff members. Effective collaboration additionally requires effective communication between the people that are involved, and cycles where the collaboration is evaluated and refined. Finally, time and physical space were required to support teacher communication, while workload was considered to be the biggest barrier for designing and implementing more suitable revision sessions. In the case of this particular collaboration, even though the project received backing and encouragement from the senior leadership, the structure of the school day and the school year still made it difficult to implement the intervention. In most instances the students have preferred revising these topics together due to similar content, finding this approach more interesting, helping develop an improved understanding, and providing more time to revise and consolidate knowledge. Finally, in regard to RQ3, the topic on moments was the one that was most successfully answered in the post-intervention physics assessment, and one that observed the greatest number of positive shifts in the level of confidence, which might hint that this topic is more suitable for collaborative revision than the other two.

This collaboration might be considered as conditionally sustainable for a number of reasons. Firstly, students overwhelmingly thought that these kinds of sessions should also be carried out in the future, provided that they cover a wider range of topics, and involve questions of progressing difficulty. Secondly, the teachers were also positive about collaborating in the next academic year, provided that there is dedicated time and

space allocated to collaboration and they can work together on teaching, rather than revising mechanics (or a completely different topic). These two conditions might prove difficult and will require support from the senior leadership team. Unfortunately, lack of clear benefits of such collaborations on student attainment might make it difficult to justify such needs.

This study provides a number of implications for my own professional practice as well as offers suggestions for future research. First of all, this study provided a strong enough base for similar kinds of collaborations to take place in the future. In a setting where little collaboration takes place, and where people have positive attitudes towards working together, such short interventions might help develop a more coherent community of practice and serve as a way of enabling continuous professional development. This in turn could lead to improved teaching, and improved student attainment, and other benefits. A way of incorporating such an incentive could be through establishing a lunch-time open teacher forum for staff to meet and discuss various issues, actively seeking discussions with teachers in different departments, and advocating for a dedicated time during a week for different curriculum groups to meet and collaborate. In terms of suggesting improvements to collaborative revision sessions, these could cover a wider range of topics, progress in difficulty, and vary in activity type. Additionally, interdepartmental collaboration could also look at teaching rather than revising of an overlapping topic.

Future research could build on this research by specifically focusing on the concepts of task design and the transfer of knowledge in their design of study. Additionally, specific links and collaborative efforts between mathematics and other disciplines (chemistry, biology, etc.) could also be explored. A way of scaling up this kind

of research would be to look to establish a form of collaboration with the senior leadership team which could aim to evaluate the effectiveness of various structural changes on teacher collaboration and the (resulting) student attainment. Finally, students might also be given more autonomy in terms of what kind of sessions they would like to participate in. These could involve sessions where teacher collaboration informs student collaboration, or vice versa, interventions where student collaboration informs teacher collaboration. Overall, there are numerous questions that are still unanswered in this field of study and in their efforts, researchers should also look to adapt some of the existing theoretical frameworks and terminologies.

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Appendix 1 – Teacher questionnaire

Teacher questionnaire

Project: "Interdepartmental collaboration for A-level mathematics and physics revision"

* Required

* This form will record your name, please fill your name.

1. What is your name? *

2. From the list of overlap topics, please list, in order of preference, the ones you would like to collaborate on. *

3. Please, justify your answer. *

4. Are these the same topics that you think your students would benefit the most from revising? *

5. Please, justify your answer. *

6. In general, what do you think about teacher collaboration? *

7. What are your experiences (positive and/or negative) with teacher collaboration? *

8. What effect do you think teacher collaboration can have on you? *

9. What effect do you think teacher collaboration can have on the students? *

10. Is there anything else that you would like to add to your responses? *

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Microsoft Forms

Appendix 2 – Student questionnaires (beginning of lesson)

Student questionnaire (beginning of lesson)

Project: "Interdepartmental collaboration for A-level mathematics and physics revision"

* Required

* This form will record your name, please fill your name.

Revision topic

SUVAT

1. What is your name? *

2. When was the last time you encountered this topic? *

- ◯ This past week
- ◯ Within the last month
- ◯ More than a month ago
- ◯ More than three months ago

3. How confident are you with this topic in: *

	Not at all confident		Somewhat confident		Very confident
Physics	◯	◯	◯	◯	◯
Maths	◯	◯	◯	◯	◯

4. Please, justify your answer. For example, it might have to do with how long it has been since you reviewed this topic, or whether you have fully understood it when you first learned it? *

Diagnostic questions

Please, answer all the questions.

5. A student is asked to solve the following problem:
   An object is thrown upwards with a speed of 25 m/s. How high will it be when the speed is 12 m/s?
   Which equation will allow the problem to be solved in a single calculation? * (1 Point)

   - ◯ $s = ut + \frac{1}{2}at^2$
   - ◯ $s = (u + v)t/2$
   - ◯ $v = u + at$
   - ◯ $v^2 = u^2 + 2as$

6. A marble is dropped from the roof of a building and takes 3.2s to reach the ground. The approximate height of the building is * (1 Point)

   - ◯ 16m
   - ◯ 31m
   - ◯ 50m
   - ◯ 100m

7. A ball is thrown vertically upwards with a velocity of +3.0 m/s. At the maximum height, the acceleration of the ball is * (1 Point)

   - ◯ 0 m/s^2
   - ◯ - 3 m/s^2
   - ◯ + 9.8 m/s^2
   - ◯ - 9.8 m/s^2

8. A ball is dropped from rest from a building 35.0m high. If air resistance is neglected the ball hits the ground with a speed of * (1 Point)

- ◯ 8.4 m/s
- ◯ 13.1 m/s
- ◯ 18.5 m/s
- ◯ 26.2 m/s

9. A ball is kicked, giving it an initial velocity v at an angle of 35° to the vertical. The ball remains in the air for a time t. Which of the following gives the distance travelled over the ground? * (1 Point)

- ◯ $vt\cos 35°$
- ◯ $\frac{v\cos 35°}{t}$
- ◯ $vt\ \sin 35°$
- ◯ $\frac{v\sin 35°}{t}$

10. Would you like to change any of your answers to the questions from the first section? *

- ◯ Yes
- ◯ No

Appendix 3 – Student questionnaires (end of lesson)

Student questionnaire (end of lesson)

Project: "Interdepartmental collaboration for A-level mathematics and physics revision"

* Required

* This form will record your name, please fill your name.

1. What is your name? *

2. How would you rate your current confidence with this topic in: *

	Not at all confident		Somewhat confident		Very confident
Physics	◯	◯	◯	◯	◯
Maths	◯	◯	◯	◯	◯

3. How useful did you find this session in terms of helping you improve your understanding of the topic? *

	Not useful at all		Somewhat useful		Very useful
Usefulness of the session	◯	◯	◯	◯	◯

4. To what extent do you think it was the effect of: *

	Very little extent		Neutral		Very large extent
Working on both subjects at the same time?	◯	◯	◯	◯	◯
The task that you have completed and reviewed during the lesson?	◯	◯	◯	◯	◯

5. Would you have preferred to work on this topic separately for maths and physics? Please, briefly explain your answer. *

6. Do you think future students would benefit from a session like this? Please, explain your answer. *

Appendix 4 – Task specifications

Task 1 - SUVAT

Physics

9.	be able to use the equations for uniformly accelerated motion in one dimension: $s = \frac{(u+v)t}{2}$ $v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
15.	understand how to make use of the independence of vertical and horizontal motion of a projectile moving freely under gravity

Mathematics

7.3	**Understand, use and derive the formulae for constant acceleration for motion in a straight line.** Extend to 2 dimensions using vectors.	**Derivation may use knowledge of sections 7.2 and/or 7.4** Understand and use *suvat* formulae for constant acceleration in 2-D, e.g. $\mathbf{v} = \mathbf{u} + \mathbf{a}t$, $\mathbf{r} = \mathbf{u}t + \frac{1}{2}\mathbf{a}t^2$ with vectors given in $\mathbf{i} - \mathbf{j}$ or column vector form. Use vectors to solve problems.

Task 2 – Newton's 1st and 2nd law of motion

Physics

17.	be able to use the equation $\sum F = ma$, and understand how to use this equation in situations where m is constant (Newton's second law of motion), including Newton's first law of motion where $a = 0$, objects at rest or travelling at constant velocity *Use of the term terminal velocity is expected*

Mathematics

8.1	**Understand the concept of a force; understand and use Newton's first law.**	**Normal reaction, tension, thrust or compression, resistance.**
8.2	**Understand and use Newton's second law for motion in a straight line (restricted to forces in two perpendicular directions or simple cases of forces given as 2-D vectors);** extend to situations where forces need to be resolved (restricted to 2 dimensions).	**Problems will involve motion in a straight line with constant acceleration in scalar form, where the forces act either parallel or perpendicular to the motion.** **Problems may involve motion in a straight line with constant acceleration in vector form, where the forces are given in $\mathbf{i} - \mathbf{j}$ form or as column vectors.** Extend to problems where forces need to be resolved, e.g. a particle moving on an inclined plane.

Task 3 - Moments

Physics

23.	be able to use the equation for the moment of a force, moment of force = Fx where x is the perpendicular distance between the line of action of the force and the axis of rotation

Mathematics

9.1	Understand and use moments in simple static contexts.	Equilibrium of rigid bodies. Problems involving parallel and non-parallel coplanar forces, e.g. ladder problems.

Appendix 5 - Usefulness of the revision sessions reported by student.

Student	Task	Task type	Usefulness of the session overall?	Useful due to working on both subjects at the same time?	Useful due to the task that you have completed and reviewed during the lesson?
1	SUVAT	NCT	Somewhat useful	Little extent	Large extent
	Newton's Laws	CT	Fairly useful	Neutral	Large extent
	Moments	NCT	Somewhat useful	Neutral	Neutral
2	SUVAT	CT	Fairly useful	Large extent	Large extent
	Newton's Laws	NCT	Somewhat useful	Neutral	Neutral
	Moments	CT	Fairly useful	Neutral	Large extent
3	SUVAT	CT	Somewhat useful	Neutral	Neutral
	Newton's Laws	NCT	Very useful	Very large extent	Very large extent
	Moments	NCT	Very useful	Very large extent	Very large extent
4	SUVAT	NCT	Very useful	Neutral	Large extent
	Newton's Laws	NCT	Fairly useful	Large extent	Large extent
	Moments	CT	Fairly useful	Large extent	Large extent
5	SUVAT	NCT	Fairly useful	Neutral	Neutral
	Newton's Laws	CT	Very useful	Neutral	Neutral
	Moments	CT	Somewhat useful	Large extent	Large extent
6	Newton's Laws	CT	Fairly useful	Neutral	Neutral
	Moments	NCT	Somewhat useful	Neutral	Neutral
7	SUVAT	NCT	Somewhat useful	Neutral	Little extent
	Newton's Laws	NCT	Somewhat useful	Neutral	Neutral
	Moments	CT	Fairly useful	Neutral	Large extent
8	SUVAT	CT	Somewhat useful	Neutral	Neutral
	Newton's Laws	CT	Very useful	Large extent	Large extent
	Moments	NCT	Somewhat useful	Large extent	Neutral
9	SUVAT	CT	Very useful	Large extent	Large extent
	Newton's Laws	CT	Fairly useful	Large extent	Large extent
	Moments	CT	Somewhat useful	Neutral	Neutral
10	SUVAT	NCT	Fairly useful	Large extent	Large extent
	Newton's Laws	NCT	Somewhat useful	Large extent	Neutral
	Moments	NCT	Very useful	Neutral	Neutral

Appendix 6 - Confidence shifts and time since last encounter of the topics in physics and mathematics by task type and topic.

Student	Task	Total points	Last time since seeing the topic?	Task type	Confidence shift (physics)	Confidence shift (mathematics)
1	SUVAT	5	This past week	NCT	No effect	No effect
	Newton's Laws	3	Within the last month	CT	No effect	Negative
	Moments	5	Within the last month	NCT	Negative	No effect
2	SUVAT	5	This past week	CT	No effect	No effect
	Newton's Laws	5	This past week	NCT	Positive	No effect
	Moments	4	This past week	CT	Positive	Positive
3	SUVAT	4	More than three months ago	CT	No effect	No effect
	Newton's Laws	4	More than three months ago	NCT	No effect	No effect
	Moments	3	More than three months ago	NCT	Positive	Positive
4	SUVAT	3	More than three months ago	NCT	No effect	No effect
	Newton's Laws	4	More than a month ago	NCT	Positive	Positive
	Moments	3	More than a month ago	CT	Positive	Positive
5	SUVAT	3	Within the last month	NCT	No effect	No effect

	Newton's Laws	5	This past week	CT	No effect	No effect
	Moments	3	Within the last month	CT	No effect	No effect
6	Newton's Laws	5	This past week	CT	Negative	No effect
	Moments	4	This past week	NCT	Negative	Negative
7	SUVAT	4	This past week	NCT	Positive	No effect
	Newton's Laws	5	This past week	NCT	No effect	No effect
	Moments	5	More than three months ago	CT	No effect	No effect
8	SUVAT	5	Within the last month	CT	Negative	No effect
	Newton's Laws	5	More than a month ago	CT	Positive	No effect
	Moments	5	More than three months ago	NCT	Positive	Positive
9	SUVAT	4	Within the last month	CT	No effect	No effect
	Newton's Laws	5	Within the last month	CT	Positive	Positive
	Moments	3	Within the last month	CT	Negative	Positive
10	SUVAT	3	This past week	NCT	Positive	No effect
	Newton's Laws	4	This past week	NCT	Positive	Negative
	Moments	5	Within the last month	NCT	Positive	No effect

Appendix 7 – Comments on tasks completed by students.

Student	Task	Task type	Task comments
1	SUVAT	NCT	Completed all questions correctly with little assistance.
1	Newton's Laws	CT	Completed all questions correctly with little assistance.
	Moments	NCT	Completed most questions correctly without assistance, except for an open response question (assumptions/mathematics).
2	SUVAT	CT	Completed most questions correctly without assistance, except for the first question on deriving the equations of motion (mathematics).
	Newton's Laws	NCT	Completed most questions correctly without assistance, except for an open response question (assumptions/mathematics), indicating a language barrier.
	Moments	CT	Completed most questions correctly without assistance, except for an open response question (assumptions/mathematics).
3	SUVAT	CT	Completed most questions correctly without assistance, except for the first question on deriving the equations of motion (mathematics), and one worded calculation question (physics), indicating language barrier.
	Newton's Laws	NCT	Completed most questions correctly without assistance, except for an open response question (assumptions/mathematics), indicating a language barrier.
	Moments	NCT	Completed most questions correctly without assistance, except for an open response question (assumptions/mathematics).
4	SUVAT	NCT	Completed all questions correctly with little assistance, except for one calculation question (mathematics).
	Newton's Laws	NCT	Completed most questions correctly without assistance, except for an open response question (assumptions/mathematics), indicating a language barrier, and a calculation question (physics).
	Moments	CT	Completed most questions correctly without assistance, except for an open response question (assumptions/mathematics).
5	SUVAT	NCT	Completed all questions correctly with little assistance, except for one calculation question (mathematics).
	Newton's Laws	CT	Completed most questions correctly without assistance, except for an open response question (assumptions/mathematics), indicating a language barrier.
	Moments	CT	Completed most questions correctly without assistance, except for an open response question (assumptions/mathematics).

6	Newton's Laws	CT	Completed all questions correctly with little assistance.
	Moments	NCT	Completed all questions correctly with little assistance.
7	SUVAT	NCT	Completed most questions correctly without assistance, except for one worded calculation question (physics).
	Newton's Laws	NCT	Completed most questions correctly without assistance, except for an open response question (assumptions/mathematics).
	Moments	CT	Completed most questions correctly without assistance, except for an open response question (assumptions/mathematics).
8	SUVAT	CT	Completed most questions correctly without assistance, except for the first question on deriving the equations of motion (mathematics).
	Newton's Laws	CT	Completed most questions correctly without assistance, except for an open response question (assumptions/mathematics).
	Moments	NCT	Completed most questions correctly without assistance, except for an open response question (assumptions/mathematics), and a calculation question (physics).
9	SUVAT	CT	Completed most questions correctly without assistance, except for the first question on deriving the equations of motion (mathematics).
	Newton's Laws	CT	Completed most questions correctly without assistance, except for a calculation question (mathematics), an open response question (assumptions/mathematics), and a calculation question (physics).
	Moments	CT	Completed the mathematics part correctly and without assistance but did not complete the physics part.
10	SUVAT	NCT	Completed all questions correctly without assistance.
	Newton's Laws	NCT	Completed most questions correctly without assistance, except for a calculation question (mathematics), a response question (assumptions/mathematics), and a calculation question (physics).
	Moments	NCT	Completed most questions correctly without assistance, except for an open response question (assumptions/mathematics), and a calculation question (physics).

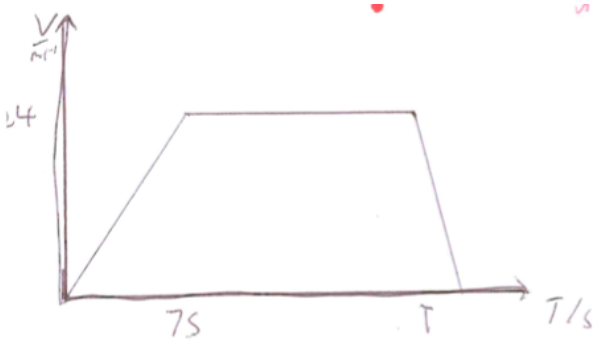
Appendix 8 – Analysis and comments on physics assessment.

Student	SUVAT	Newton's law	Moments
1	5/6 - well answered, lost mark in the written response part – it did not contain enough information.	0/4 - did not understand what 'negligible effect on mass' meant for the question.	2/2 - well answered.
2	6/6 - well answered.	3/ 4 - well answered, missed one piece of information on Newton's 3rd law.	2/2 - well answered.
3	2/6 - did not recognise the SUVAT question here, indicating a language barrier.	2/4 - well answered, missed one piece of information on Newton's 3rd law, and not explicitly stating Newton's 1st and 2nd law.	2/2 - well answered.
4	1/6 - poorly answered, due to mistakes in applying trigonometry.	4/4 - well answered.	2/2 - well answered.
5	1/6 - poorly answered, due to mistakes in applying SUVAT equations, and not recognising that the initial velocity is 0 m/s, indicating a language barrier.	1/4 - poorly answered, only having stated Newton's 1st law, recognising that an unbalanced force will lead to a change in velocity.	2/2 - well answered.
6	3/6 - relatively well answered, lost marks in finding horizontal distance for a parabolic trajectory.	2/4 - relatively well answered, an answer indicating good knowledge of what Newton's laws are, but lacking detail in explanation.	2/2 - well answered.
7	1/6 - poorly answered, did not recognise the SUVAT nature of the question.	2/4 - relatively well answered, an answer indicating good knowledge of what Newton's laws are; made mistakes applying the laws and lack detail).	2/2 - well answered.
8	6/6 - well answered.	3/4 - well answered, lost mark due to lack of distinction between acceleration and deceleration.	2/2 - well answered.
9	5/6 - well answered, lost mark due in finding horizontal distance for a parabolic trajectory – forgetting to multiply by 2.	4/4 - well answered.	2/2 - well answered.
10	6/6 - well answered.	3/4 - well answered, lost mark due to lack of distinction	2/2 - well answered.

		between acceleration and deceleration.	

Appendix 9 – SUVAT responses from Student 10.

NCT



b) $S = 0.6\,km$
$u = 24$
$v = 0$
$a = a$

$v^2 = u^2 + 2as$
$0 = 24^2 + 2 \times a \times 600$
$-576 = 1200a$
$a = -0.48\,ms^{-2}$

the deceleration of the train was $0.48\,ms^{-2}$

c) $S = s$
$u = 0$
$v = 24$
$at = 75$

$s = \left(\frac{0+24}{2}\right)75$ → So before T and after 75s, train travel
$S = 900m$
$7500 - 900 - 600$
$= 6000m$

$S = 6000m$
$u = 24$
$v = 24$
$t = T$ → $6000 = \left(\frac{24+24}{2}\right)T$

$T = \frac{6000}{24} = 250s$

$\therefore T = 250 + 75$

$T = 325$ seconds

d) total time

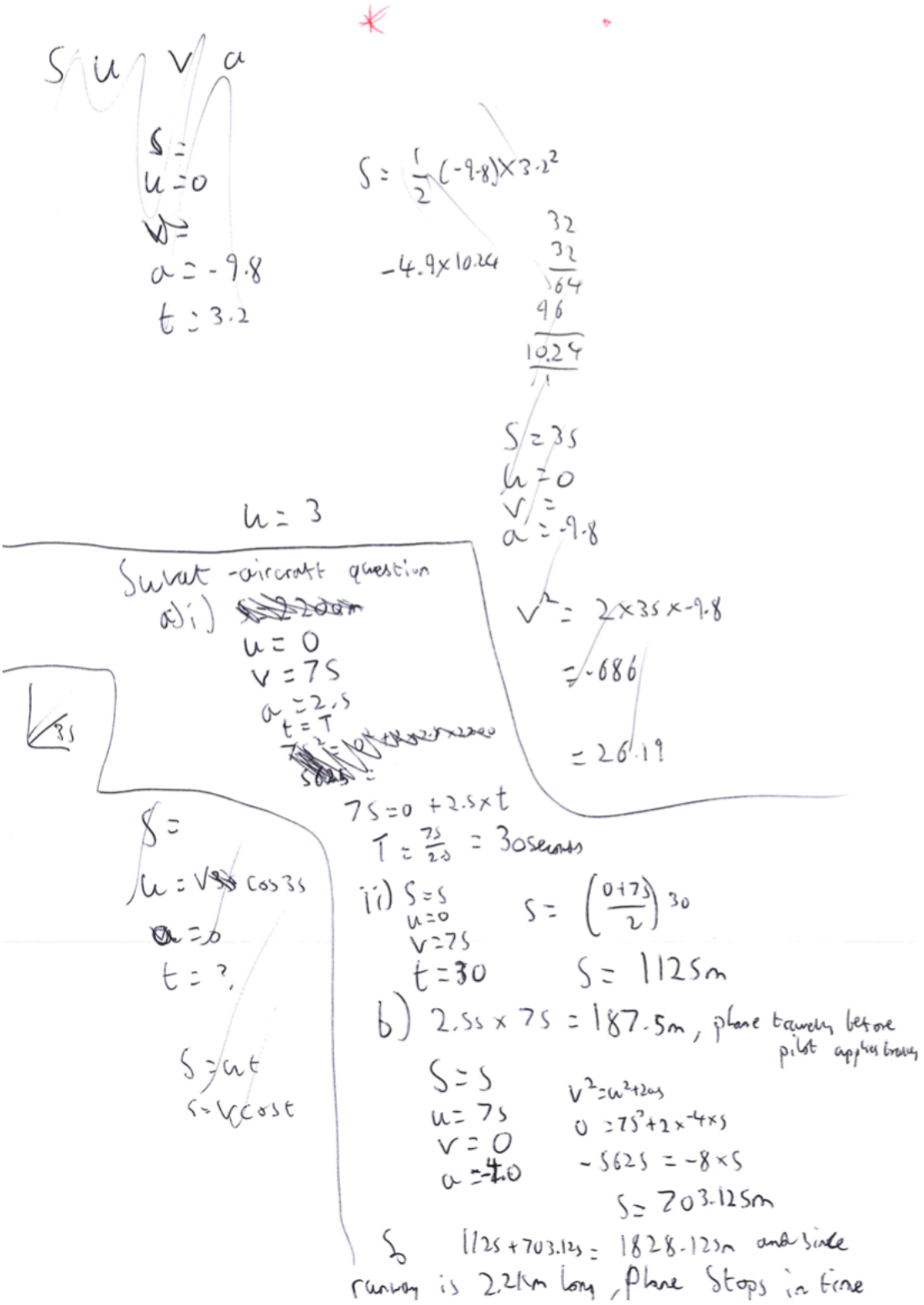
$S = 0.6km$
$u = 24$
$v = 0$
$t = T$

$0.6 = \left(\frac{24+0}{2}\right)T$

$T = \frac{600}{12} = 50$ seconds

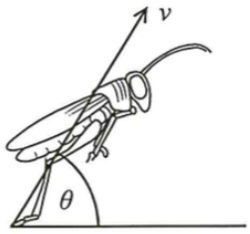
[illegible] journey time

$\therefore$ Total time for journey is 375 seconds


S u v a
S =
u = 0
v =
a = -9.8
t = 3.2
S = 1/2 (-9.8) × 3.2²
-4.9 × 10.24
32
32
64
96
10.24
S = 35
u = 0
v =
a = -9.8
u = 3
V² = 2 × 35 × -9.8
= -686
= 26.19
Swiat - aircraft question
a) i)
u = 0
v = 75
a = 2.5
t = T
75 = 0 + 2.5 × t
T = 75/2.5 = 30 seconds
S =
u = V cos 35
a = 0
t = ?
S = ut
S = V cos t
ii) S = S
u = 0
V = 75
t = 30
S = (0+75)/2 30
S = 1125m
b) 2.55 × 75 = 187.5m, plane travels before pilot applies brakes
S = S
u = 75
V = 0
a = -4.0
V² = u² + 2as
0 = 75² + 2 × -4 × S
-5625 = -8 × S
S = 703.125m
1125 + 703.125 = 1828.125m and since runway is 2.2km long, plane stops in time

14 Grasshoppers can jump up to twenty times their length to escape predators. The magnitude of the launch velocity v does not vary significantly for a given grasshopper, so the length of the jump mostly depends on the launch angle θ.

The diagram shows a grasshopper at the instant it launches.



(Source: adapted from http://gclipart.com/grasshopper-clipart_28241/)

(a) The grasshopper jumps from rest on level ground. The launch velocity is $2.6\,m\,s^{-1}$ at an angle of 57° to the horizontal.

(i) Show that the vertical component of the launch velocity is about $2\,m\,s^{-1}$.

(1)

$2.6 \times \sin 57 = 2.18 = 2.2\,ms^{-1}$ ✓1

(ii) Assess whether the horizontal distance travelled by the grasshopper in the jump is about 20 times the grasshopper's length.

length of grasshopper = 5.0 cm

(5)

vertically $u = 2.2$ using $v = u + at$ ✓5

$v = 0$ $0 = 2.2 - 9.8 \times t$

$a = -9.81$ $-2.2 = -9.8 \times t$

$t = t$ $t = 0.22\,s$ use more sig figs

$s = s$ So total t is $2 \times t = 0.44$ ✓

$u = 2.6 \times \cos 57$

$a = 0$ $s = ut + \frac{1}{2}at^2$ ✓2

$t = 0.44$ $s = 2.6\cos 57 \times 0.44 + \frac{1}{2} \times 0 \times 0.44^2$

$s = 2.6\cos 57 \times 0.44$

$= 0.62\,m$ ✓

$0.62 \div 5 \times 10^{-2} = 12.4\times$ ∴ The horizontal distance isn't 20 times the grasshopper's length it is only 12 times.

Appendix 10 – Letter to the headteacher

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Director Professor Jo-Anne Baird

[Headteacher]

Wednesday, 8 December 2021

Dear [Headteacher],

I am writing to enquire about conducting research in school this academic year. As you know, I am studying for the Master's in Learning and Teaching at Oxford University, supervised by [Supervisor]. In my final research project "Interdepartmental collaboration for A-level mathematics and physics revision" I will look to establish sustainable collaboration practices between maths and physics teachers for A-level mathematics and physics revision.

The project will bring together teachers to develop resources that would help A-level students to prepare for exams, in a way that is not disadvantageous to the maths department. The collaboration will take form of a task design session and revision lessons that will be prepared jointly by maths and physics teachers. This intervention will comprise of 3-4 cycles and will involve exploring teacher and student perceptions through questionnaires and semi-structured interviews, as well as student progress by analysing student responses to diagnostic questions. [Head of department] has agreed to collaborate with me on this.

By participating in the research, the school would be contributing to a project that will deepen our understanding of interdepartmental collaboration between mathematics and physics and its effect on student perceptions and learning. It will also contribute to mathematics and science education more widely.

I hope to conduct this research between January 2022 and June 2022 This study would comprise of 3-4 cycles and will involve exploring teacher and student perceptions through questionnaires and semi-structured interviews, as well as student progress by analysing student responses to diagnostic questions.

Oxford University has strict ethical procedures on conducting ethical research, consistent with current British Educational Research Association guidelines. The University also recognises, however, that my study is a piece of practitioner research, and that schools already operate with the highest ethical standards. Therefore only your formal consent as headteacher is necessary, and not that of individual parents or staff. However, throughout the research, students and other teachers will be able to refuse to participate in any research activities at any time.

All participants, including students, teacher and the school, would be made anonymous in all research reports. The data collected would be kept strictly confidential, available only to my [Supervisor] and me, and only used for academic purposes. It will be kept for as long as it has academic value.

If you are happy for me to proceed with this study, please confirm that using the attached reply form. If you have any concerns or need more information about what is involved, please contact me or my supervisor. Further, if you have any questions about this ethics process at any time, please contact the chair of the department's research ethics committee, though: research.office@education.ox.ac.uk

I look forward to hearing from you.

Yours sincerely,

[Author]